Journal

WATER POLLUTION CONTROL FEDERATION

Special Features

1960 Literature Review, Part I—Research Committee
Analytical Methods, Sewage

Research in Water Pollution Control—Hanson and Berger

Radioactive Wastes—Foster et al.

Chlorine Determinations—Rand et al.

Treatment of Organic Cyanides—Ludzack et al.

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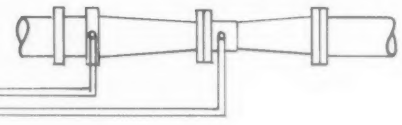

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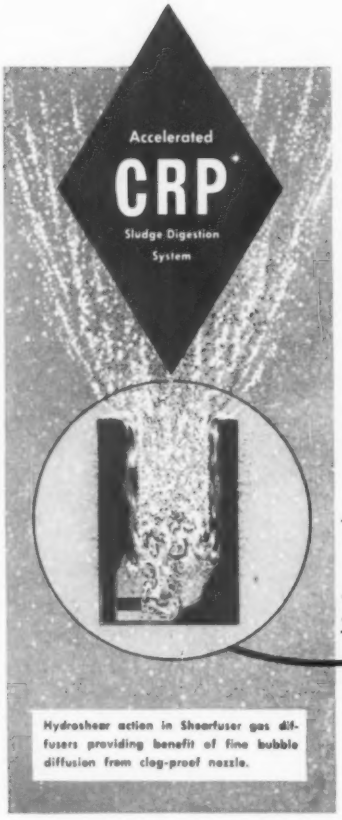

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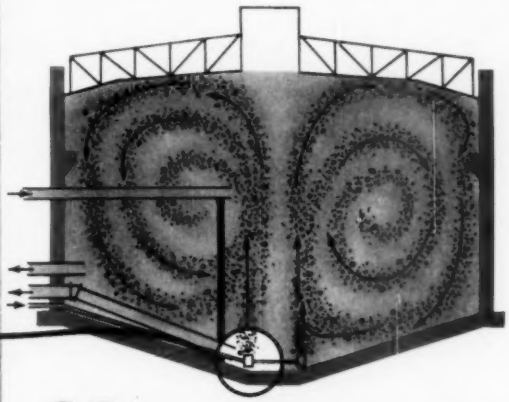

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Volume 33 | May 1961 | Number 5

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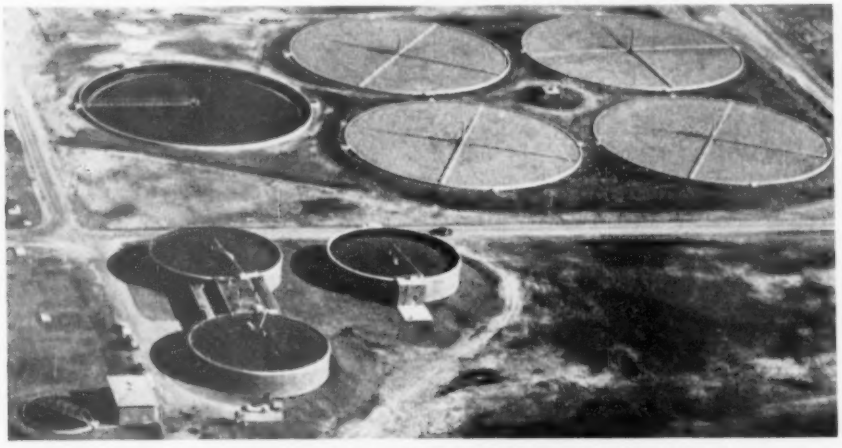

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Alabama	June 5–7	University of Alabama, University
New England	June 7–8	Snow Inn, Harwichport, Mass.
Central States	June 7–9	Leland Hotel, Springfield, Ill.
Iowa	June 7–9	The New Inn, Okoboji
Ohio	June 14–16	Statler-Hilton Hotel, Cleveland
ISP (England)	June 19–23	Brighton, England
Pennsylvania	Aug. 9–11	Pennsylvania State University, State College
New Zealand	Aug. 28–29	Metro. Drain. Bd. Conf. Rm., Auckland, New Zealand
Kentucky-Tennessee	Sept. 11–13	Brown Hotel, Louisville, Ky.
Germany	Sept. 12–16	Hamburg, Germany
Georgia	Sept. 20–22	Georgia Institute of Technology, Atlanta
South Dakota	Sept. 20–22	Sheraton Hotel, Rapid City
Missouri	Oct. 1–3	Kentwood Arms Hotel, Springfield
North Dakota	Oct. 4–6	Gladstone Hotel, Jamestown
Florida	Oct. 29–Nov. 1	Cherry Plaza Hotel, Orlando
Nebraska	Nov. 8–9	Hotel Lincoln, Lincoln
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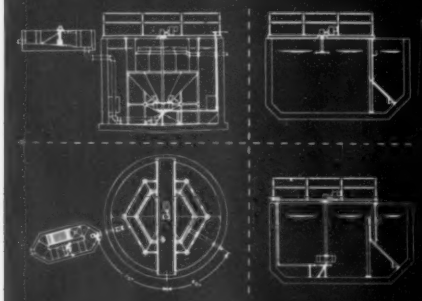

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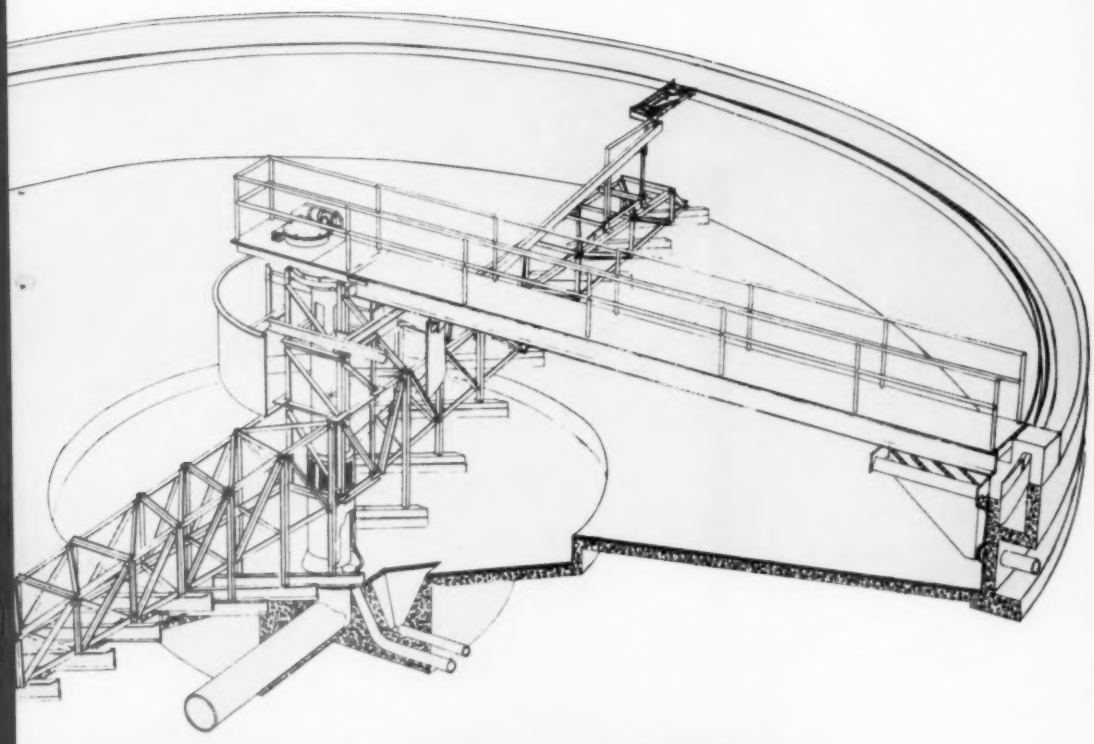

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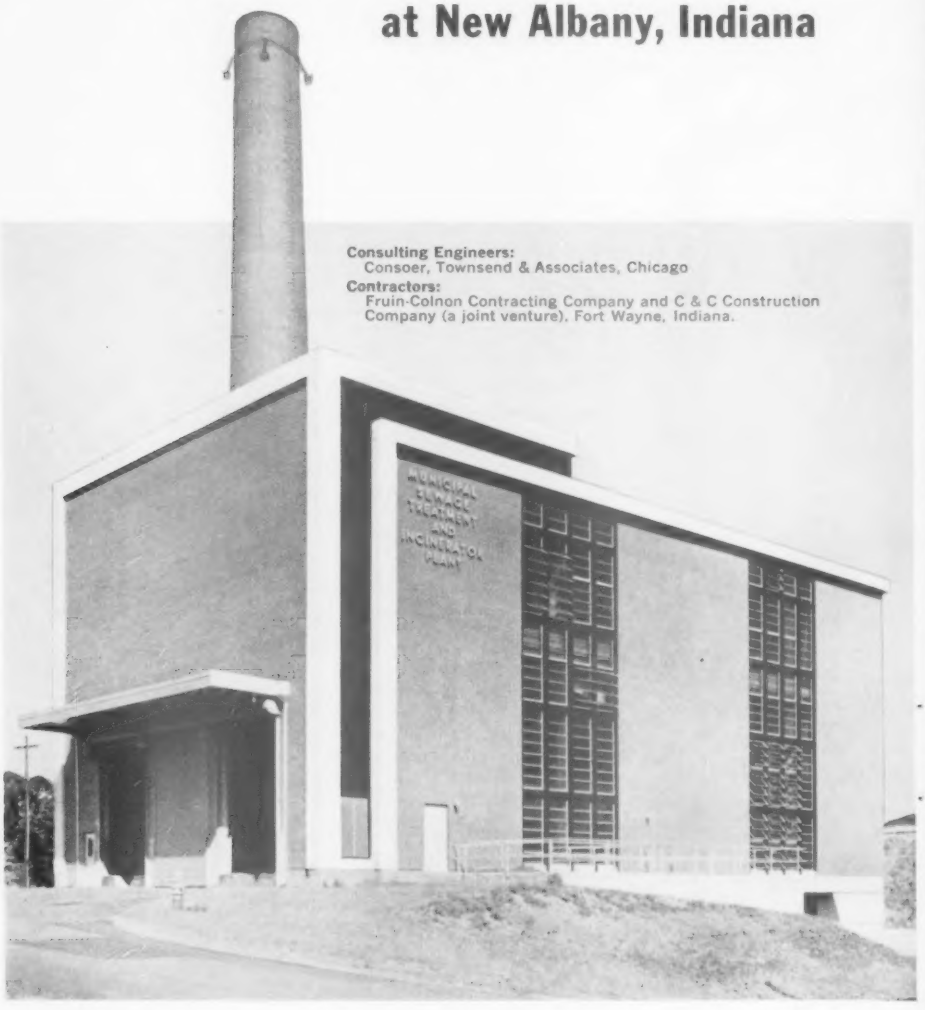
Waste incinerator heat dries sewage in combined plant at New Albany, Indiana



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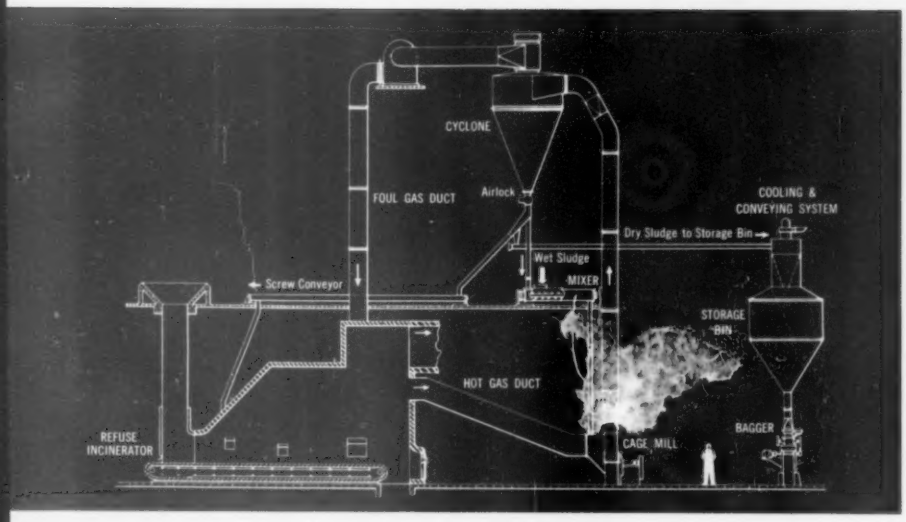


New municipal plant teams up C-E Incinerator Stokers with C-E Raymond Flash Dryer System to dispose of mixed refuse and sewage sludge.

The City of New Albany, Indiana, recently placed in operation a single plant which combines *both* mixed refuse and sewage sludge disposal functions.

Heart of this 2-in-1 disposal system is the C-E Incinerator Stoker, which continuously burns the refuse it receives from its self-sealing, non-clogging hopper. The refuse is reduced to a sterile, clinker-free ash suitable for use as sanitary land fill.

"No cost" heat from the burning refuse is used to dry sewage sludge in the C-E Raymond Flash Dryer. No auxiliary fuel is needed to reduce sludge filter cake to 8 per cent moisture content. The dried sludge is bagged for sale as a soil conditioner. When desired, any portion of the sewage sludge may be incinerated with the refuse. The New Albany plant contains two Incinerator-Dryer combination units.

More and more communities – large and small – are looking into the many cost-saving possibilities of treating both refuse and sewage sludge at the same plant site. C-E specialists will be glad to discuss your requirements with you and your consultants. You are invited to write to your nearest C-E office. No obligation, of course. C-294A

COMBUSTION ENGINEERING

Raymond Division: 427 West Randolph Street, Chicago, Ill. Western Office: 615 So. Flower St., Los Angeles 17, Calif.
New York Office: 200 Madison Avenue, New York 16, N. Y. CANADA: Combustion Engineering-Superheater Ltd.

PAPER MILL EQUIPMENT; PULVERIZERS; FLASH DRYING SYSTEMS; PRESSURE VESSELS; SOIL PIPE

NICHOLS "ROTO-PLUG"* SLUDGE CONCENTRATORS

NOW A COMPLETE SLUDGE DISPOSAL SYSTEM

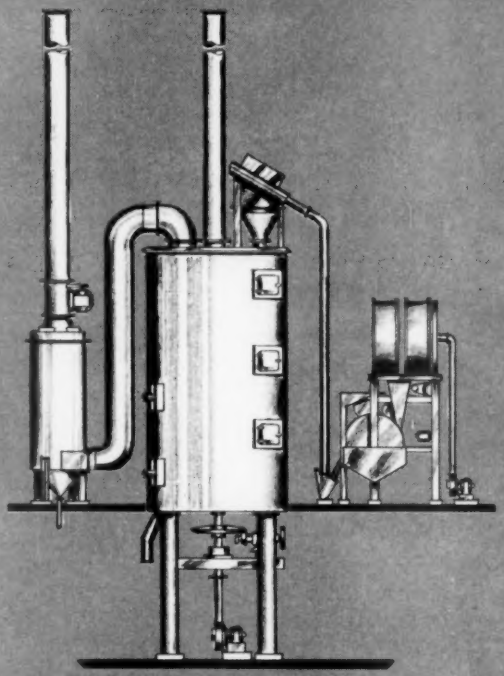
NICHOLS

Engineering & Research Corp.

80 Pine Street, New York 5, New York

*Equipment Development Corp.

NICHOLS HERRESHOFF FURNACES



COMPLETE DESTRUCTION—The Nichols system destroys all putrescible solids.

CLEAN—All gases scrubbed before discharge to atmosphere complying with the most stringent air pollution requirements. Enclosed tubular conveyor eliminates spillage of sewage solids in disposal area.

Furnace ash is sterile, inert, completely odor free; packs firmly, providing excellent fill material.

SAFE—Since no chemicals are required, corrosive materials affecting equipment and personnel are eliminated. Least danger of explosion.

COMPACT—A Nichols Package Process serving up to 10,000 people requires an area about that of a two-car garage!

ECONOMICAL—Low first cost. Operating savings: No chemicals, very low power, very low maintenance, little personal attention required.

Undigested sludge is autocombustible.

For complete details write for folder RP 100 and Catalog 238.

3513 N. Hovey Street, Indianapolis 18, Ind.

1336 North Carolan Ave., Burlingame, Calif.

you can't

PATCH IT!

Some things can't be patched, let's face it. Among them are a bond issue and a sewer line. If either fails, you start all over again—and that's expensive.

If your city puts inferior sewer pipe in the ground—and gases and acids ruin it—somebody's got to dig it up and replace it. That costs you—the taxpayer—a whole lot more money than putting down lifetime pipe in the first place.

Putting in an inferior sewer pipe is a real penny-wise, pound-foolish idea, anyway. The big cost of putting in a sewer line is tearing up streets and digging the ditch, NOT the pipe. Actually the pipe—the best, lifetime pipe—averages about only 12 percent of the cost of the job.

Lifetime pipe is Vitrified Clay Pipe. It can save you untold tax dollars in the long run.

No, you can't patch a sewer line any more than you can a bond issue. But you can patch a hole in your money pocket—and the time to patch it is before you've lost a lot of money. That means demanding lifetime pipe—Vitrified Clay Pipe—for the next sewer line in your community.

Public health is important. Your city may need to upgrade its sewer lines.

Find out how by writing to:

NATIONAL CLAY PIPE MANUFACTURERS, INC.
1028 Connecticut Ave., Washington, D. C.

Please send me full details on the new factory-made compression joints on Clay Pipe.

(name)

(company)

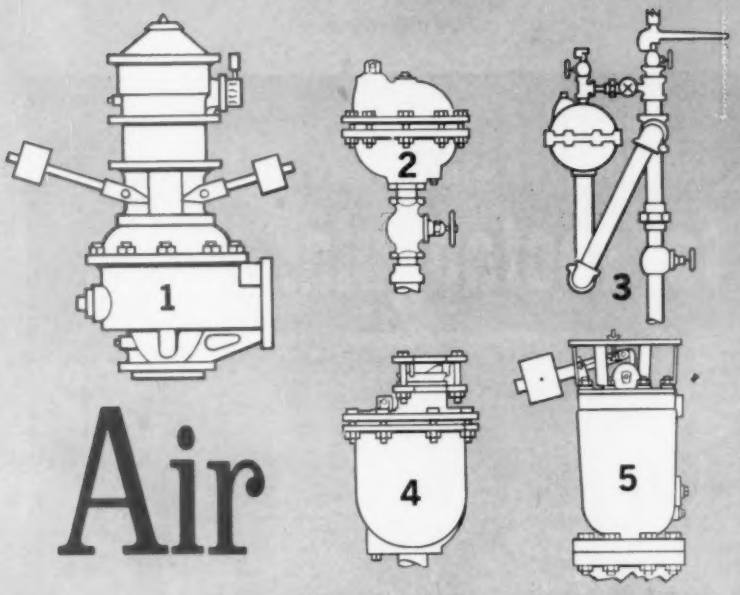
(street address)

(city and state)

B-41 WP

COMPRESSION SEALED, VITRIFIED
CLAY PIPE
IMPERVIOUS
THE STANDARD in SANITARY SEWERS

NATIONAL CLAY PIPE MANUFACTURERS, INC.
1028 Connecticut Avenue, N.W.
Washington 6, D. C.



Air

How to protect your pipeline from too much or too little of it.

1. Prevents water hammer: Type CCAV Controlled Closing Air Valve protects against damaging effects of surge and water hammer. Combines functions of an air inlet valve (vacuum breaker) and a controlled closing unit (to prevent sudden water stoppage and subsequent water hammer). 4" and 6" sizes. Capacities from 575 to 5980 gpm. Send for Bulletin 1225.

2. Removes excess air: Type AGFD Automatic Air Release Valve prevents stoppages due to air-lock at high points in line. Has large discharge capacity, excess power to insure opening of the valve against high internal pressure. Can be equipped to hold vacuum, preventing re-entry of air into pipeline through valve. Furnished with 2", 1½" or 1" inlet diameter. Standard valve operates to 250 psig—special to 300 psig. For details, send for Bulletin 1206.

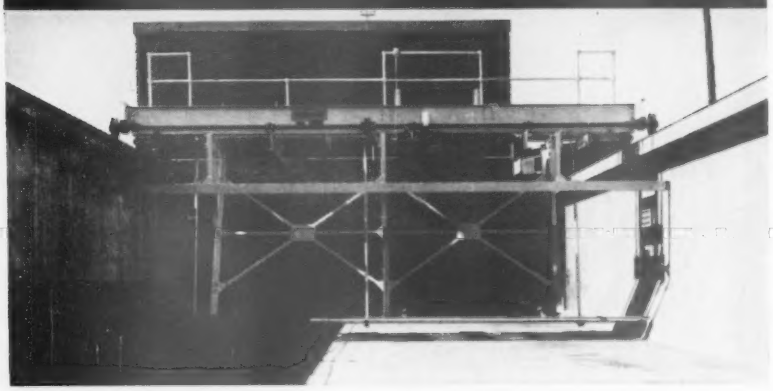
3. Protects sewage pipelines: Type "B" Air Release Valve, special for lines carrying sewage or sludge, removes entrained air and gases. Special trap catches sludge, prevents fouling of air release valve. Relatively simple back-flushing cleans out this trap, maintains top efficiency and protection. Valve itself is same as Type AGFD. Details are in Bulletin 1206.

4. Provides three functions: Type AV Air Release and Air Inlet Valve performs three operations, combines great protection and single-unit economy: (1) Automatically releases accumulated air, (2) admits air to break vacuum, and (3) vents pipeline to permit escape of air when filling system with water. Standard units operate to 150 psi. For full details, send for Bulletin 1205.

5. Breaks vacuums: Type VAC Air Inlet Valve solves two serious pipeline problems: possible collapse of pipelines due to formation of vacuums—and stoppage of flow, caused by air binding when lines are being filled. Standard units have 4" to 10" inlet diameters, can be assembled in groups to do the work of one large, expensive valve. For detailed information send for Bulletin 1200.

SIMPLEX
VALVE AND METER COMPANY
a division of PFAUDLER PERMUTIT INC.
Lancaster, Pennsylvania

HARDINGE CLARIFIERS for rectangular tanks



The Hardinge Rectangular-Type Clarifier is similar in operation to an industrial, overhead crane. It travels on two rails, on the outside walls of the settling tank, scraping settled solids to a sludge hopper at one end. A skimmer may be added to remove scum and floating material from the tank surface on the "return trip" of the Clarifier.

Advantages of the Hardinge unit are these:

(1) Settling tank installations may be made in limited space (as opposed to the circular type clarifier).

(2) Maximum use of common wall construction is possible, when there are two or more tanks involved.

(3) A single Clarifier mechanism can operate over two adjacent settling tanks (duplex arrangement) reducing equipment cost.

(4) Clarifier equipment cost does *not* increase with tank length.

(5) All essential working parts are above liquid level.

Hardinge has installed more than 80 Rectangular Clarifier units for municipal sewage treatment, industrial water treatment, and for liquid wastes at paper plants, textile mills, and oil refineries—processing in excess of 350 million gallons of liquid daily.

Write for Bulletin 35-D-16.

HARDINGE

COMPANY, INCORPORATED

Main Office and Works • 240 Arch St., York, Pa.

"Hardinge Equipment—Built Better to Last Longer."

NEW YORK
TORONTO
CHICAGO
HIBBING
SALT LAKE CITY
SAN FRANCISCO
HOUSTON
LAKELAND
BIRMINGHAM

"Flexible" CAM DRIVE UNIRODER

An entirely new principle providing Non-Slip Rod Drive!

NO ROLLERS TO SCORE OR BURN

ANOTHER "Flexible" FIRST!

PAT. PENDING

UniRodeR Model SUR-1 rods sewers and is ideal for threading cable for bucket machines

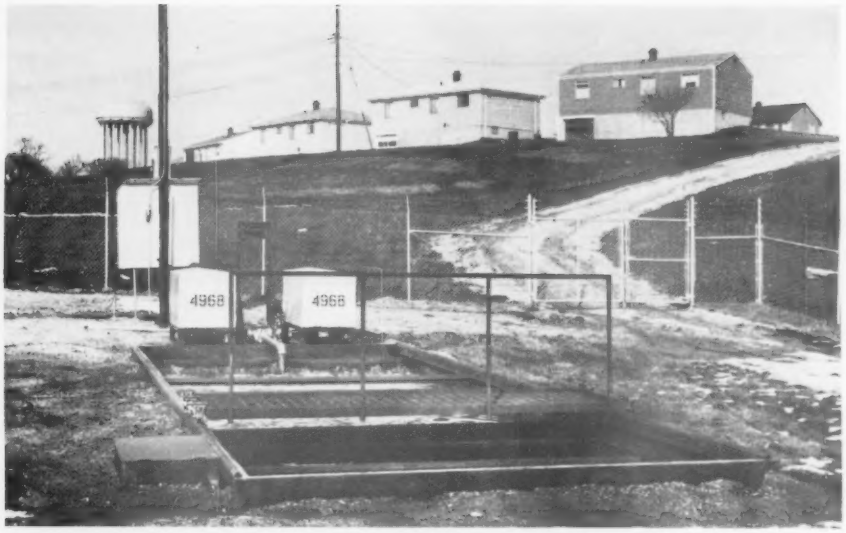
CAMS GRIP TIGHTER UNDER LOAD

Revolutionary! Traveling cams push or pull the continuous rod, rotating with it in either direction. The heavier the load the tighter the cams grip the rod. NO FRICTION ROLLERS TO SCORE OR BURN. Exclusive Safety Overload Clutch protects pipe, machine and rod. Simplified mechanism and fewer working parts mean less maintenance than any other continuous rodder!

- 8 Speeds Forward or Reverse
- Positive Non-Slip Cam Drive
- Capacity up to 2000 ft.
- Tool Box, 3 cu. ft. Capacity
- All Moving Parts Enclosed
- Safety Overload Clutch
- Footage Meter
- Uses From ¼ to ⅜-in. Rod
- 9 hp. with Self Starter

FLEXIBLE INC.

415 S. Zangs Blvd., Dallas, Texas
Factories: Los Angeles, Calif. and Lima, Ohio



Kansas City North

This 17,500-gallon-per-day "Oxigest" sewage treatment plant is equipped with two motor-driven blowers with variable speeds for control of the air supply and has a movable walkway across the tank for ready access to all parts of the treatment plant.

S&L

ACTUALLY, this is a dual "Oxigest" installation in Kansas City North, Mo., serving a growing subdivision being developed by Bolling-Hausman Development Co., Kansas City, Mo. The plant was specified by Raymond W. Campbell & Associates, Merriam, Kansas.

It is a good example of units being installed in parallel, as needed, to serve an expanding residential area. The unit on the left was installed in the spring of 1960 . . . the other unit, late last fall.

Write for engineering data: Address Dept. 30.

Smith & Loveless

ONE OF THE UNION TANK CAR COMPANIES

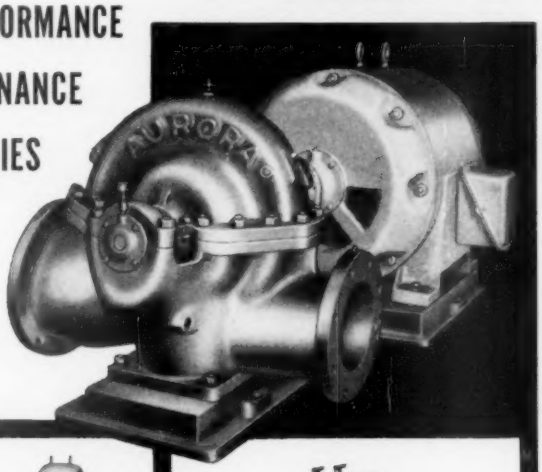
P.O. BOX 8884 / KANSAS CITY 15, MISSOURI / PLANT: LENEXA, KANSAS

AURORA® Split Case

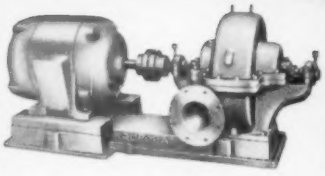
CENTRIFUGAL PUMPS

with

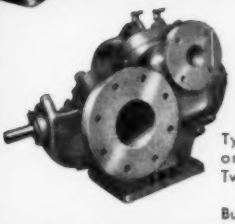
- SMOOTH PERFORMANCE
- EASY MAINTENANCE
- HIGH CAPACITIES



Type OJ Horizontally Split Single Stage Double Suction. Bulletin 105-B.



Type AJ Horizontally Split Two Stage Opposed Suction. Bulletin 106-B.



Type AJ Diagonally Split Two Stage

Bulletin 106-DS

- Smooth, dependable performance and long life is assured with streamlined liquid flow, scientifically balanced impellers, perfect alignment, large shaft sizes, short bearing centers and low NPSH.
- Maintenance is fast and easy . . . both suction and discharge are on bottom half of case . . . piping and motor-pump alignment is never disturbed.
- Capacities to 600 GPM . . . Heads to 600 feet.

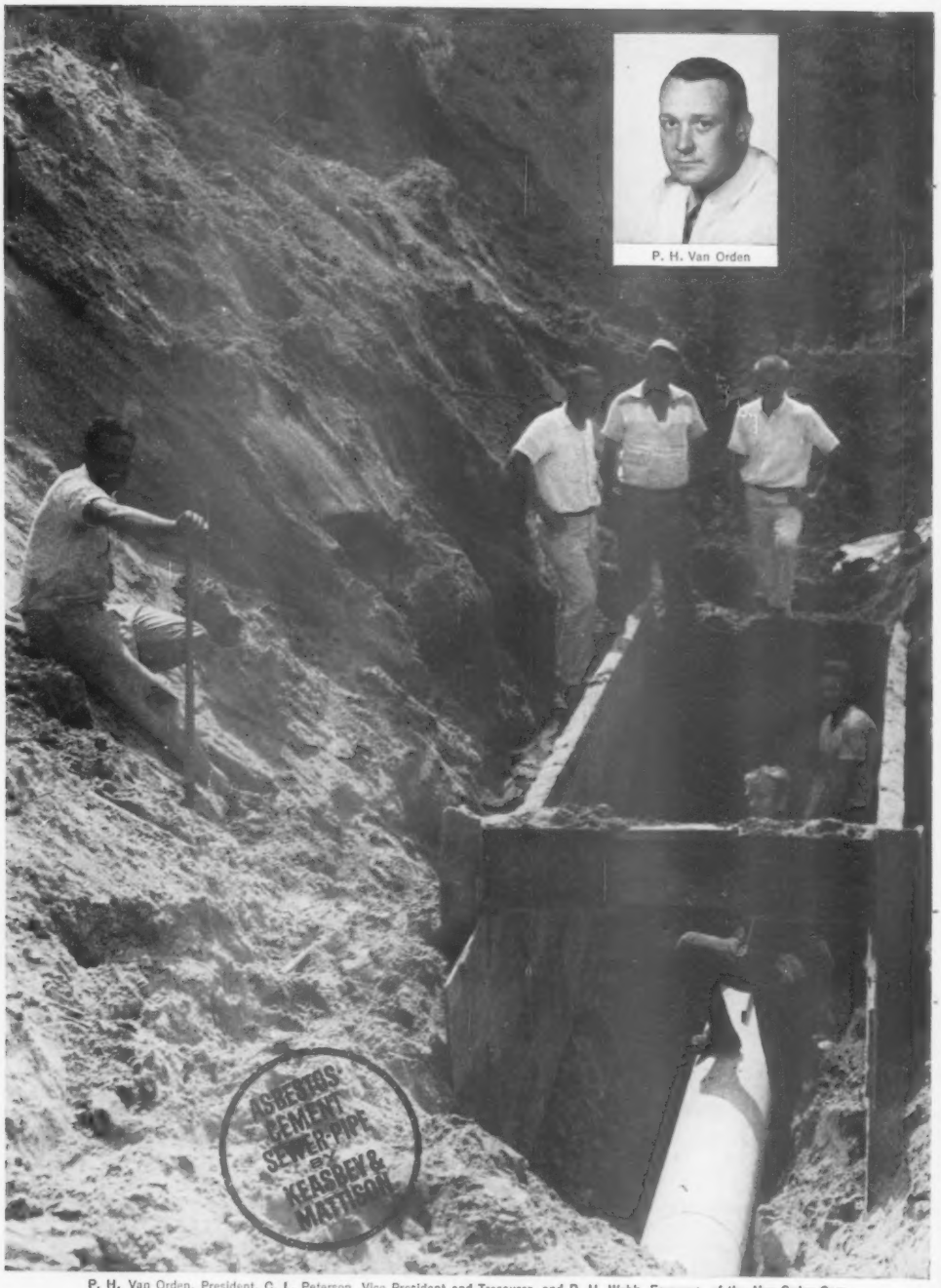
IDEAL FOR: Water Service • Boiler Feed • Circulating • Cooling Tower • Pressure Build-Up • Fuel Transfer • Boosting to Pressure or Elevated Tanks • Many General Applications.

FOR COMPLETE INFORMATION WRITE—OR CALL

AURORA Always PUMPS

AURORA PUMP DIVISION
THE NEW YORK AIR BRAKE COMPANY ®
1190 LOUCKS • AURORA, ILLINOIS

LOCAL DISTRIBUTOR IS LISTED IN THE YELLOW PAGES OF YOUR PHONE BOOK



P. H. Van Orden, President, C. L. Peterson, Vice President and Treasurer, and R. H. Webb, Foreman, of the Van Orden Company, Contractors, of Grand Rapids, Mich., supervise the installation of "K&M"® Asbestos-Cement Sewer Pipe at Paw-Paw, Mich.

10,000 FT. OF SEWER PIPE LAID

...Not enough infiltration to measure

"The ease of handling and assembly saved us dollars and time! Construction of the Paw-Paw trunk sanitary sewer called for installation of pipe at depths up to 19 feet, where water table was at 10 feet. Infiltration had been the major problem in other sewer installations in the area. We solved this problem by using "K&M" Asbestos-Cement Sewer Pipe with its FLUID-TITE joint. With 10,000 feet of sewer in, we haven't had enough infiltration to measure.

"The longer laying lengths and the speed with which a joint can be made are definite time-saving factors, which have added to our production. Less time spent grading pipe and handling material means dollars saved."

Rigorous tests prove "K&M" Asbestos-Cement Sewer Pipe is infiltration-tight at 25 psi . . . a pressure equivalent to that of a 58-foot head of water.

"K&M" Asbestos-Cement Sewer Pipe won't rust, rot or corrode. Its smooth bore remains clean, permanently. Flatter grades are possible. Fewer lift stations are required.

Maintenance-wise, the village of Paw-Paw, Mich., will enjoy tax savings. "K&M" Asbestos-Cement Sewer Pipe is practically indestructible. Requires fewer inspections, because root growths do not penetrate the exclusive FLUID-TITE coupling.

Write today for more information on "K&M" Asbestos-Cement Sewer Pipe to: Keasbey & Mattison Company, Ambler, Pa., Dept. P-1751.

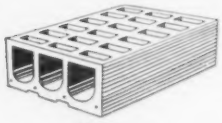
Keasbey & Mattison at Ambler

K·M BEST IN ASBESTOS

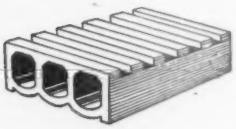
Light weight reduces shipping and handling costs . . . saves on installation time. At the same time, there's a minimum of wastage and breakage on the jobs, with tough "K&M" Asbestos Cement Sewer Pipe.

Two-step assembly! Lubricate the tapered end of "K&M" Asbestos-Cement Sewer Pipe, then slide it into the exclusive, patented "K&M" FLUID-TITE® Coupling.

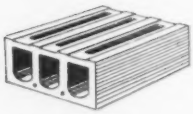
Why Trickling Filters Succeed for SEWAGE and WASTES TREATMENT



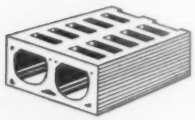
DICKEY
W. S. Dickey Clay Mfg. Co.
Kansas City 6, Mo.



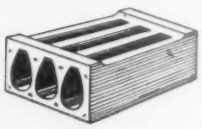
TRANSLOT
Texas Vitrified Pipe Co.
Mineral Wells, Texas



POMONA
Pomona Terra-Cotta Co.
Pomona, No. Car.



BOSCO
Bowerston Shale Co.
Bowerston, Ohio



NATCO
Natco Corporation
Pittsburgh 22, Pa.

FOR FULL DATA WRITE NEAREST MEMBER.

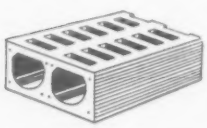
Nearly 1,000 new trickling filters went into service between 1945 and 1957. The building-pace continues unabated. This is a direct reflection of their economy in construction and efficiency in operation. For many of these filters are working as well today as when first built, even those thirty and more years old. Costly remodeling and rebuilding have been avoided. And no other type is easier to add to if growth exceeds your original estimate.

The most vital part of a trickling filter is its underdrain system. When it is of TFFI specifications vitrified clay blocks life-time, trouble-free service is assured. Specify in accordance with ASTM Specifications C 159-59T and you are safe for years to come.

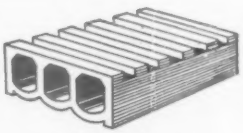
TFFI Specification clay blocks not only serve right, they are made right—in modern plants under manufacturing controls of quality that substitute materials cannot even approach. (Only with TFFI blocks do you get a 50-Year Guarantee.)

DEMAND CERTIFIED UNDERDRAIN BLOCK

Vitrified Clay Block manufactured by TRICKLING FILTER FLOOR INSTITUTE members and tested by the Materials Testing Laboratory of Rose Polytechnic Institute comply with or exceed ASTM Specification C 159-59T.

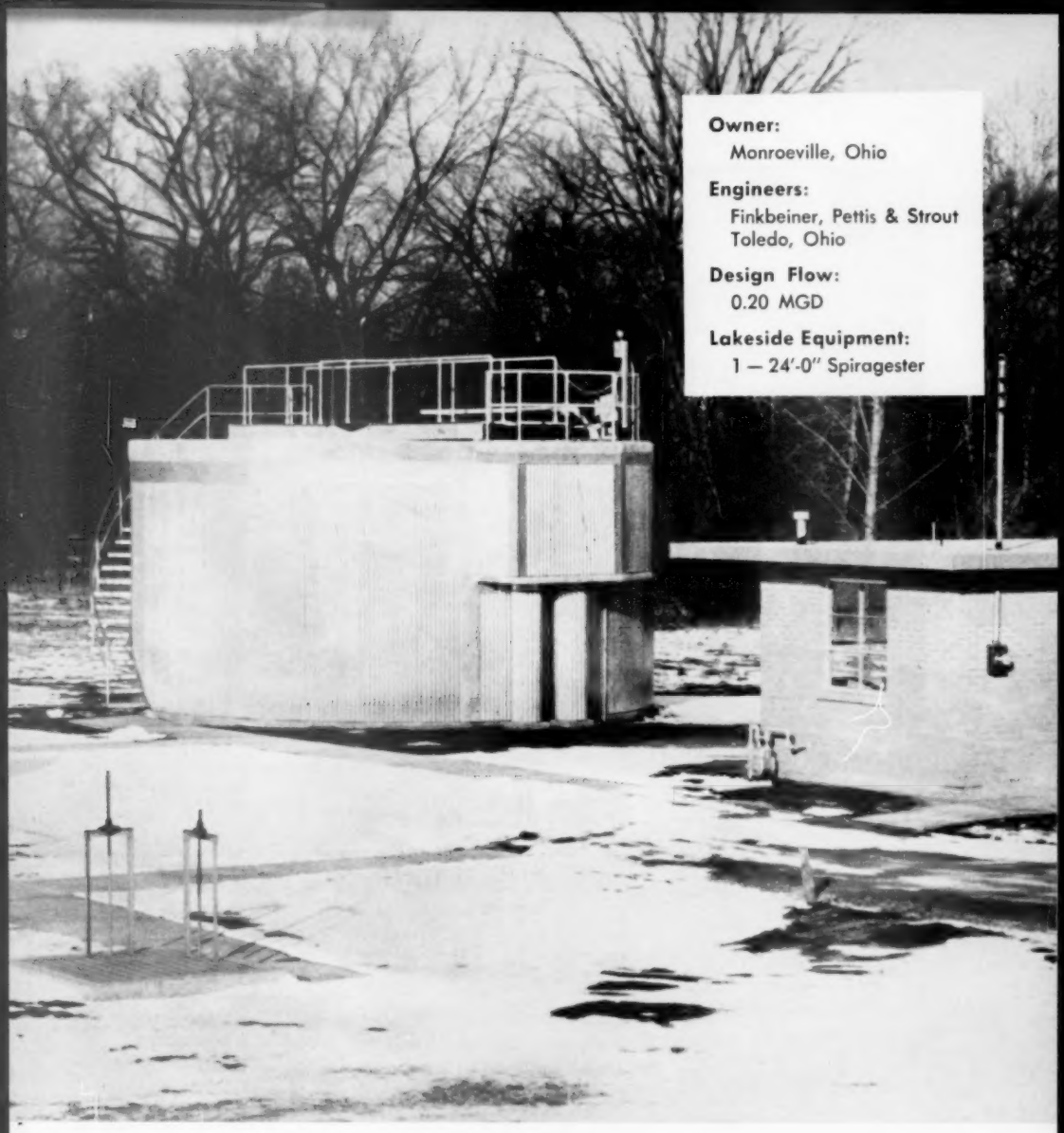


ARMCRE
Ayer-McCarel Clay Co., Inc.
Brazil, Ind.



TRANSLOT
Connelton Sewer Pipe Co.
Connelton, Ind.

The Trickling Filter Floor Institute

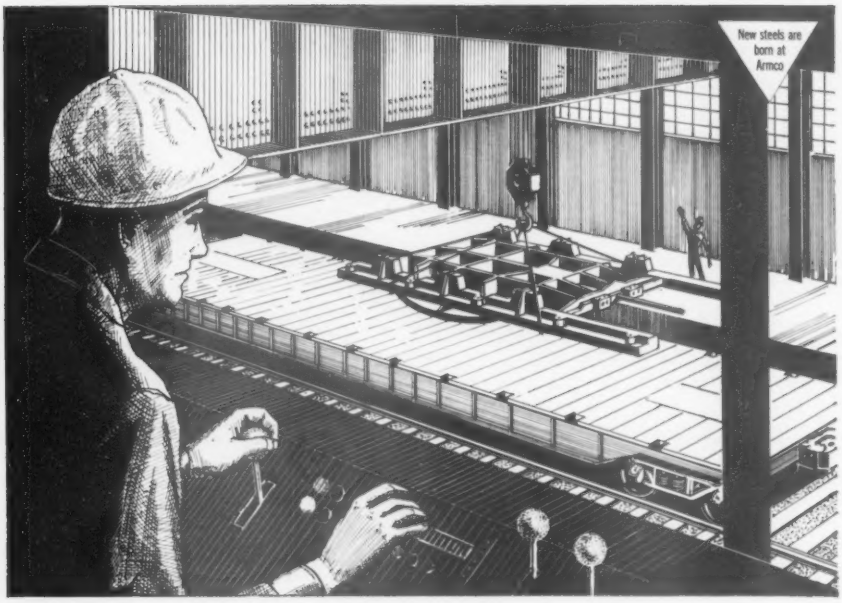


SPIRAGESTERS are used singly for projects under 6000 P.E. They give superior results with the minimum of operating skill. Construction and operating costs are among the lowest. Plant expansion available by adding another Spiragester or easily converting the tank to a digester. Spiragesters are now installed throughout the U.S. Also Canada and foreign countries. At Monroeville only primary treatment is required. A low over-all cost was possible with the clarifier and digester combined in the Spiragester. *Write for plant costs and booklet GIL-2 "The Spiragester Story."*

LAKESIDE

ENGINEERING CORPORATION

222 West Adams St., Chicago 6, Illinois



Steel

For rugged, dependable economy

When It Leaves On "The 3:01," Your Armco Gate Is Ready To Install

Big or small, every Armco Sluice Gate is completely assembled and adjusted before it leaves for your job site. It arrives as a self-contained unit, and can be quickly mounted by an inexperienced crew with proper supervision. There's no need for high-cost, specialized labor. Detailed instructions for final adjustment are included with *every* gate.

Low installation cost is just *one* of the advantages you get with rugged, watertight Armco Gates. Write Armco Drainage & Metal Products, Inc., 5801 Curtis Street, Middletown, Ohio, for the latest catalog.

ARMCO Drainage & Metal Products

Activated Sludge Thickened to 4% (and more) with Rex Float-Treat®

This remarkable thickening rate was obtained with two Rex Float-Treat Thickeners installed in two pilot unit tanks, 13′4″ wide by 60′ long, at the Bay Park Treatment Plant, Nassau County, N. Y.

In fact, runs of substantial duration resulted in solids concentration greater than 5%—far exceeding the performance of the existing conventional gravity system. As a result of this performance record, six additional Rex Float-Treat Thickeners were purchased.

INCREASED CAPACITY...LOWER COSTS. Thickening with Rex Float-Treat Thickeners, as compared to gravity-type systems, produces much denser sludge concentrations, with far greater loadings. This results in two important advantages: 1. thickener tanks can now be much smaller; 2. with greater sludge concentration, overloaded sludge disposal facilities are relieved—or new facilities can be smaller.

EFFICIENT OPERATION. With Rex Float-Treat Thickeners, millions of tiny air bubbles float solids to the tank surface, forming a highly concentrated sludge blanket. Skimmers move the thickened sludge to the end of the tank for disposal.

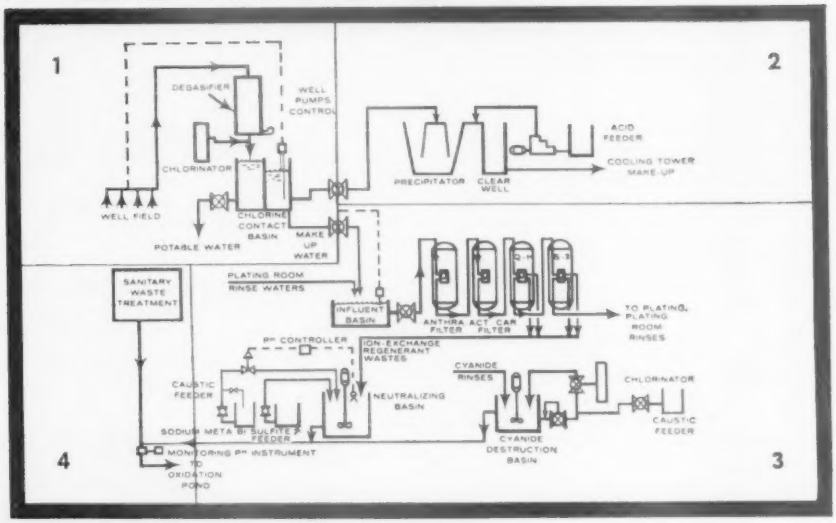
The Rex Float-Treat employs many unique features, including: thorough blending of an air-charged stream and raw sludge feed; positive distribution of solids-flow into the tank; two zones within the tank for more efficient flotation separation and sludge concentration; and generous sludge removal capacity. Air flotation thickeners with Rex Float-Treat permit classification into floatable organic solids and settleable inorganic solids.

For complete information, write CHAIN Belt Company, 4606 W. Greenfield Ave., Milwaukee 1, Wis.

REX®
CHAIN BELT COMPANY

Rex Float-Treat Thickeners, Bay Park Sewage Treatment Plant, Nassau County, Long Island. Consulting Engineers, Greeley and Hansen. Plant Superintendent, August Zoeller.

FLUIDICS* AT WORK



How many of these water and waste treatment ideas can you use profitably?

From water source to waste disposal this new system now serving the Electro-Mechanical Research Company, Sarasota, Florida, is packed with ideas that can help *you* solve similar problems—and each idea was brought to reality with equipment supplied by Permutit.

1. Well-water treatment (upper left in diagram) handles a minimum flow of 160 gallons per minute from a well field—84 gallons for industrial cooling, 10 gallons for plating rinse make-up, and the balance for potable use. All this raw water is degasified and treated in a Permutit equipment system.

2. Cooling water undergoes further treatment (top right) for reduction of carbonate and bicarbonate alkalinity, by means of a Permutit® Precipitator and acid feeder.

3. Plating room rinse-water demineralizing (center and lower right). A complete Permutit system saves water, saves heat, treats regenerant wastes, and provides high-quality demineralized water for plating rinse. Make-up and plating rinse water is processed through an anthracite filter to remove suspended solids, a Carbo-Dur filter to remove organics, a Permutit Q-H cation exchanger, and a Permutit S-2 anion exchanger. This demineralized water is then ready for use. After plating rinse operations, water is recycled, treated and re-used. Wastes—including cyanide rinses, regenerants, and others—are batch treated.

4. Sanitary waste treatment (lower left) was designed to handle 20,000 gallons per day, treating them first in an Imhoff tank, followed by high-rate bio-filtration, secondary clarification and chlorination.

The entire system was engineered by Smally, Wellford and Nalven, Sarasota, Florida. We can cooperate with your engineering consultants to help you obtain similar results. Talk it over with them, or write for our Bulletin 4433, "Water Treatment Equipment," and/or Bulletin 4486, "Equipment for Treating Industrial Wastes."

Permutit Division, Dept. JW-51, 50 West 44th Street, New York 36, New York.

PFAUDLER PERMUTIT INC.
Specialists in FLUIDICS . . . the science of fluid processes

*FLUIDICS is the Pfaudler Permutit program that integrates knowledge, equipment and experience in solving problems involving fluids.

6 reasons why...

MARLOW PLUNGER PUMPS HANDLE SLUDGE BETTER!

1 Marlow plunger type pumps are self-priming with suction lifts up to 20 feet and more.

2 Guaranteed quantity for each cycle permits Marlow Plunger Pumps to double as metering unit . . . simplifies operating cycle of treatment plant.

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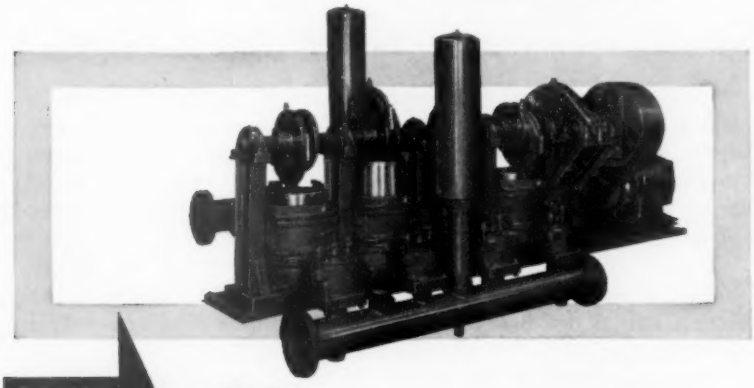

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A REVIEW OF THE LITERATURE OF 1960 ON WASTEWATER AND WATER POLLUTION CONTROL

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ANALYTICAL METHODS

Anions

A silver-silver sulfide electrode coupled with a glass electrode makes possible a potentiometric titration of sulfide and mercaptan ions in solution according to Tamele *et al.* (47). The sulfides and mercaptans are precipitated with silver until no further changes are observed in current flow. Plotting the results permits differentiation of the sulfides and mercaptans.

In the colorimetric determination of phenols in wastewater sulfides must be removed to prevent reaction with ferricyanide. The sulfides may be removed with silver according to Gordon (11); an excess of chloride ions prevents the presence of an excess of the silver which reacts first to form the less soluble sulfide.

Chromatographic separation and partial identification of volatile acids have been reported by two laboratories. Mueller *et al.* (31) have studied river waters where it is necessary to evaporate the samples to dryness at a high pH and then use ether extraction of the residues. Column partitioning as well as paper chromatography are used. Buswell *et al.* (4) have described the technique for a quick check on the volatile acids in digesting mixtures. The concentrations of volatile acids can be approximated by the intensity of a spot while the distance traveled permits tentative identification of the acid.

The determination of the total concentration of the iodide, cyanide, and sulfide ions can be obtained at pH 6 by adding an excess of mercuric nitrate according to Hoffmann (18). The excess of mercury is determined by adding one drop of one-per cent diphenylcarbazone solution. In a second tube

The authors comprise the Research Committee of the Water Pollution Control Federation.

This section of the Literature Review covers analytical methods and sewage. It will be followed by two other sections dealing with industrial wastes (including radioactivity) and stream pollution. These will be published in the June and July issues of the Journal.

the buffer and indicator are titrated to a matching color intensity with a mercuric nitrate solution.

The determination of dihydric phenols, resorcinol, is carried out with catechol and iodine. By extracting the color with butanol Lure's and Nikolaeva (27) have increased the sensitivity of the test over the absorbency in a water acetone mixture.

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Biochemical Oxygen Demand

The search for a means of recording oxygen uptake during a normal incubation period has been solved by Clark (6). The BOD is measured in a large reaction vessel with oxygen gas in equilibrium with the culture medium. The changes in gas pressure resulting from oxygen uptake are transposed to a variable electrical current which can be recorded. The pressure transducer is a common item in the electrical engineer's tools and thus provides a means of evaluating and recording the oxygen demand in equipment like the direct reading, Warburg respirometer.

In comparisons between manometric and 5-day dilution BOD values, Dillingham and Jose (8) have found that 18-hr manometric results show good correlation with the 5-day values by either the manometric or by the dilution techniques. These results were obtained with paper mill wastes over a wide range in concentration.

Two articles presented mathematical techniques for calculating the ultimate first-stage demand and the rate of the biological activity. Sheehy (41) presents two different graphical approaches while Navone (32) uses another graphical procedure to handle daily BOD data.

Chemical Oxygen Demand

The University of California Sanitary Engineering Laboratory (49) has modified the chromate COD to shorten the time required for analysis.

Because many think that the COD should determine only the organic matter, nitrites may be considered as an interference. Thus, Subrahmanyam *et al.* (46) have suggested the addition of a few crystals of sulfamic acid as a means of removing nitrites before adding the chromate reagent in determining the COD.

Henningan and Nemerow (16) suggest a new approach to sewage analysis. A solvent would be chosen to extract some of the organic matter from the sewage and the residue of the solvent solution weighed. The concept of extraction differs from the idea of total oxidation by the dichromate COD in that the solvent should extract only the biologically available organic matter while the total oxidation shows no differentiation between inert and available matter.

Cyanide

Because of the extreme toxicity of cyanide the analytical procedures for this compound are continuously reviewed. Brin (3) reports that the use of chloroform instead of butanol speeds the process of getting results. The aqueous solution is added to the cuvette and chloroform is added which can extract the color. Transmission of the light through the underlying chloroform layer is measured directly. Using a new analytical tool, Hetman (17) describes the determination of cyanide by the cathode ray polarograph. High concentrations of chloride do not interfere. The presence of sulfide and free chlorine or bromine do interfere. The method is both sensitive and precise.

The differentiation of toxic from nontoxic forms of cyanide has been studied by Russell and Wilkinson (38). The cyanide is separated from the cyanate, ferrocyanide, and ferricyanide by a distillation step. The ferricyanide and ferrocyanide are sequestered by a zinc salt. A refinement of the tartaric acid

procedure for separating cyanides has been recommended by Schlichting (40). Care must be used to maintain pH 4 to 5 in order to exclude the effects of high salt concentrations.

Dissolved Oxygen

Ridley *et al.* (37) describe a colorimetric titrimetric recorder which determines the dissolved oxygen in an aliquot of river sample or aeration tank every five minutes. Winkler DO reagents are injected into the sample and mixed; an excess of thiosulfate is added. A back titration of the thiosulfate with a standard iodate solution provides a DO value which is recorded. The instrument has been used successfully in studies of the Thames. LaMont and Gordon (25) have used a similar means of injecting reagents to liberate iodine, but have used a colorimeter for directly recording the iodine concentration variations.

In Germany, Stracke and Keefer's (45) continuous measurement of dissolved oxygen in aeration tanks has been accomplished polarographically with a pair of metal electrodes. The noble metal is the cathode or measuring electrode. The electrodes are cylinders and rotate at a constant speed and are cleaned by the scraping of a metal block similar to the arrangement of the brushes against the armature of an electric motor. The electrodes are kept in a stream of sample which is first screened and then pumped to the electrode chamber.

In a comparison of three procedures Okura *et al.* (33) have studied the Winkler, Miller, and polarographic techniques. The dropping mercury electrode gives higher DO values in three industrial wastes studied when the instrument had been calibrated on pure water and is considered more accurate. In contrast with this favorable report on the dropping mercury electrode, Maney and Okun (28) report that the various types of synthetic detergents have a heavy but variable interfering effect on the DO values. Anionic detergents interfere with the oxygen determination at the lower voltage wave, cationic detergents interfere with the determinations at the second voltage wave (increase in current at the higher voltage). The nonionic detergents interfere at all points. Klima (23) discusses the polarographic determination of dissolved oxygen in industrial wastes.

In a different technique, James and Stephen (20) have an electro-determination based on the electrolytic production of the chromous ion and the voltaic record of the amount needed to produce an excess of this easily oxidized ion. In this technique aliquots are introduced into the electrolysis chamber and the chromic ion injected. The quantity of electric current required to produce an excess of chromous ion is recorded.

Because the amperometric titration for chlorine readily determines iodine, Goldman and Dietz (10) have suggested this procedure for measuring the iodine concentration in the last step of the Winkler technique.

Because the new Jarrell-Ash instrument for determining dissolved oxygen depends on the per cent saturation for reporting DO, correct saturation values are highly important. Elmore and Hayes (9) have reported on values for saturation from 0° to 30°.

General

The need for identification of the source of the oily or tarry material found in the ocean and on the beaches near Los Angeles provided the stimulus to characterize the seeps (44). Crude oils and distillation residues were analyzed by infrared and chromatography. The data indicate that the seeps are natural in origin and intermediate in "age" between mud and crude oil.

The need for an instrumental evalua-

tion of the color intensity and purity of hue in a polluted stream led Smallwood and Fortune (43) to study the factors which would yield good correlations with the instrumental observations and those of the human eye. The field trials showed that both the depth of water, the bottom color as well as the stream environment, were correlated by the observer while not included by the instrument.

The Russian rivers, Volga and Oka, have been studied for their hydrobiological indexes of pollution and self-purification. Mergasova (29) has identified various fungi and protozoa.

In a discussion of the basic principles involved in ORP measurements, Kehoe and Jones (22) indicate that present instruments can evaluate the conditions in certain waste treatment processes. The numerical value indicates the ratio between the oxidized and the reduced form of a reversible system. When the chemical pair is not reversible, and/or when several systems are present simultaneously, the value obtained must be carefully considered.

Because the analysis of a gaseous by-product frequently is a guide in the more intelligent operation of waste treatment processes, and because the classical techniques of gas analysis are cumbersome and time-consuming, it is helpful to see that Grune *et al.* (13) have found a technique for rapid gas analysis. The gas chromatograph provides rapid identification and percentage composition of digester gas. The process can also indicate the optimum (most economical) amount of air needed for the aeration process of activated sludge (by finding the maximum carbon dioxide content).

The development of a rapid, simultaneous technique for the determination of water and fat in biological materials has been described by Wistreich *et al.* (51). The semi-solid sample is placed in a soxhlet thimble and immersed in a fat solvent in a special flask. The water is evaporated and collected separately in a graduated cone while fat dissolves in the solvent. The fat solution is transferred to a tared distilling flask and the solvent removed; increment in flask weight equals the fat.

The differential determination of chlorinated solvents in industrial wastes can be difficult. Deyl and Effenberger (7) recommend the degradation of the solvent by nitric and persulfuric acids. The hydrochloric acid is distilled off into a mild basic solution and the hypochlorite ion determined potentiometrically.

Because the determination of sugar uses the reduction of mild oxidizing reagents, the color developed may not be specific, but it may be very helpful in detecting serious carry-over into river water used for condensing the stream from an ejector. Baum (1) describes the instrument which takes a sample periodically from the stream, adds reagents, and notes the color intensity. The plant has an instrument on the river water and the condensed water to determine the sugar loss and stream load.

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Metals

Kroner *et al.* (24) reported on the accuracy in determining iron, copper, manganese, aluminum, cadmium, lead, chromium, and zinc by several laboratories. The present methods for aluminum and cadmium were found unsatisfactory.

The analysis of metal-bearing industrial wastes for many important metals is very time-consuming. Thus, Porter *et al.* (35) have tried polarographic scanning of metal waste samples to learn the approximate concentration of the specific metal as well as the identity and concentration of any interfering metal ions. The article

includes a discussion of difficulties and advantages.

Shull (42) has reported that fluoride and polyphosphate interfere in the aluminon method for aluminum. The polyphosphates are destroyed during evaporation of the sample to dryness to remove the fluorides. The fluorides are removed as silicon tetrafluoride. The color is temperature dependent and pH sensitive.

A new colorimetric determination for determining hexavalent (chromate) chromium is described by Halliwell (14). The oxidizing capacity of the chromate is used with a stable cadmium iodo-starch reagent. The starch iodine blue gives a reproducible intensity for colorimetric evaluation.

The determination of copper without interference from other metal ions would frequently be highly desirable. Tuck and Osborn (48) report that 2-2' biquinoline can be used for copper without interference from iron, nickel, or zinc.

The differential determination of ferrous and ferric iron requires more study according to Lee and Stumm (26). Bathophenanthroline reagent yields more stable colors than the reagent of the ninth and tenth editions of "Standard Methods." The ferrous compound with the bathophenanthroline can be extracted into a non-polar solvent for greater stability and/or sensitivity.

Mercury may be determined in industrial brine solutions with the dropping mercury electrode according to Grandi and Salvagnini (12). The mercury ions show an increase in current at about zero potential. If the sample does not have brine, it must be added before the observations are made.

Where the quantity of silver in an industrial waste must be known, Pierce (34) has provided details for the various steps that must be used to eliminate the effect of interferences. The silver is extracted into carbon tetrachloride twice as the dithiazonate and dissolved from the first extraction with ammonia water.

Zirconium can be determined with very little interference by first precipitating it with mandelic acid according to Schneer (39). The mandelic acid salt which contains four anion radicals can be filtered off and the organic matter (mandelic acid) titrated with permanganate or chromate solutions.

Nitrogen Compounds

The search for a rapid accurate procedure for nitrate concentration continues. Hartley and Asai (15) indicate that 2-6 xylenol can be used to react with nitrates in water solution directly. Chlorides and nitrites interfere, but can be removed; silver sulfate can be added in excess to remove the chloride, but the sample must be filtered; solid, crystaline sulfamic acid can be added to remove nitrites. With 1 cm light path and 1 ml sample directly the technique is not sensitive. This is increased by evaporating a larger sample to dryness before adding reagents. The color is determined in the ultraviolet at 323 mμ.

Hora and Webber (19) have found that samples of ammonium nitrate lose nitrate rapidly when the solution is evaporated to dryness without pH adjustment (near pH 6.0). A small amount of potassium hydroxide to yield pH 9.0 eliminated the nitrate loss, which was caused by the ammonium ion. The loss of nitrate at pH values near 6.0 during drying of larger samples was noticed by Hartly and Asai (15).

The quantitative conversion of nitrate to nitrite to obtain the sensitivity of the diazzo technique for the nitrite has been studied by Price and Priddy (36). Zinc is used for the reduction at pH 10. An involved procedure for determining nitrates has been proposed by Caeusescu (5). A color of indigo carmine is formed and this is back titrated with permanganate.

The determination of ammonia in coke plant wastes provides special problems. Kaplin and Fesenko (21) propose that the use of the blue indophenol color be used. Coke wastes contain both ammonia and phenol—chlorination causes the blue color to form. To reduce interferences the color molecule can be extracted from an acid solution with chloroform and reestablished in an alkaline medium in the chloroform or aqueous solution.

Bradstreet (2) has studied the various possible reducing reagents which can be added to the Kjeldahl procedure to include the organic nitrogen compounds in the higher valence states of nitrogen. Sugar is recommended over salicylic acid as a reducing agent as the preliminary step. At the other end of the determination, Milner and Zahner (30) have found sulfamic acid highly desirable for titrating small quantities of ammonia in the distillate.

In the control of an activated sludge sewage treatment plant, it would be interesting to know how effectively certain simple organic nitrogenous compounds have been removed. A rapid paper chromatographic procedure with ninhydrine has been developed by Van Benden (50) for determining the approximate concentration and identity of the amino acids in sewage and treated effluents.

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SEWAGE

Physical and Chemical Methods

Pierce (90) discussed the role of the primary sedimentation tank as the key unit and control center for the entire sewage treatment plant. By early detection of unusual characteristics of the raw sewage entering the primary tank, the operator may frequently be able to adjust his normal methods of management of this facility so that harmful effects on subsequent plant units may be minimized. The interrelationships of sedimentation tank and digester operation are discussed. The problems associated with sludge and scum removal and transfer, industrial and toxic wastes, and grit are discussed in detail.

Mahood (66) described a chemical coagulation and pressure flotation plant constructed to treat oil wastes originating in an aircraft maintenance plant. The waste consists of water contaminated with 500 to 1,200 mg/l of oil, 250 to 700 mg/l of which is in emulsified form. The BOD varies from 400 to 800 mg/l. The treatment process consists of coagulation with liquid alum and activated silica, followed by a flotation unit which operates at a surface loading up to 6,000 gpd/sq ft. The oil content of the effluent is less than 20 mg/l.

The principles of dissolved air flotation were presented in detail by Vrablick (124). The paper discusses the theories of the various processes involved in the solution, precipitation and the rise of the air bubbles, and the methods by which the flotation of suspended solids takes place. It gives typical results of experimental studies showing the relationships between the variables involved. The independent variables are (*a*) per cent suspended solids in the feed, (*b*) aeration pressure, and (*c*) retention time. The dependent variables are (*a*) suspended solids in the float, (*b*) suspended solids in the underflow, (*c*) suspended solids in the decanted liquor, (*d*) the volume of float, and (*e*) the volume of underflow. Design criteria for dissolved air flotation systems are discussed.

Biological Filtration

Two problems inherent in the operation of most biological filters are the prevention of excessive film accumulation which may result in ponding and the fly nuisance. Hawkes (37) considers these to be an ecological problem and reports a study of the effects of methods of sewage application on the ecology of the filter.

Six different methods of applying sewage to the filter were used. The modifications of the nozzles can be described as follows: open fish-tail, closed fish-tail, splash plate, an unmodified jet, twin jets, and "quad" jets. All were designed to apply an equal amount of sewage to a 24-in. strip of the filter surface. The open and closed fish-tail nozzle produced a sheet of liquid approximately 24 in. wide, the latter having the greater impinging force. The splash plate nozzle was so constructed that it delivered a circular sheet of liquid approximately 24 in. in diameter. The unmodified jet discharged a cylindrical jet approximately 1 in. in diameter. The twin jet used two circular jets spaced 12 in. apart and the "quad" jet used four ½-in. nozzles spaced 6 in. apart.

To assess the amount of surface growth, a layer of media was placed on steel mesh trays which extended 12 in. to either side of the original jet line. Perforated cylindrical cans, 6 in. in diameter and 6 in. deep and containing about 0.1 cu ft of media, were placed below the trays. These were used to assess the total amount of film below the surface and the biological fauna. Eighteen monthly samples were analyzed for each of the six nozzles between August 1956 and February 1958.

It was found that satisfactory operation of a filter requires the maintenance of an effective grazing population which prevents film accumulation as well as an even distribution of sewage over the bed surface. Of the nozzles tested the two fish-tails and the splash plate all gave even distribution. However, it was observed that the increased numbers of grazing fauna under the splash plate were more effective in reducing the film accumulation than was the impinging action of the fish-tail nozzles. The "quad" jet produced better bed conditions, even under extreme loadings, than the single or twin jet. Comparing the "quad" jet with the splash plate it was found that while the latter produced a more uniform distribution, the former created a more suitable environment which permitted the establishment of a mixed grazing fauna.

As maintenance of a mixed fauna whenever possible is to be preferred to a fauna dominated by one species it was concluded that the "quad" jet produced the most desirable ecological conditions.

An equation derived from basic trickling filter theory was proposed by Schulze (100) as a means of predicting filter efficiency. Filter loadings may be measured either hydraulically or organically. Of the two, only the former affects the length of time the sewage remains in contact with the biological slimes which are responsible for the major part of the treatment. Based on data obtained from an experimental trickling filter it was concluded that the efficiency of a filter is independent of the organic loading as long as the hydraulic load remains constant, but is dependent on the contact time which is a function of the hydraulic loading.

The equation

$$L_e/L_i = 10^{-kD/Q^{0.67}}$$

where

L_e = final effluent BOD in mg/l,
L_i = incoming waste BOD in mg/l,
D = depth of the filter in feet,
Q = hydraulic loading in mgd, and
k = $2.303K$ (K = a constant found experimentally to vary between 0.22 and 0.33),

provides a basis for computing the efficiencies of single-pass filters at any combination of hydraulic load and depth.

A study of the effects of hydraulic loadings and filter depths on the performance of trickling filters was made by Abdul-Rahim *et al.* (1).

An experimental filter, 5 ft in diameter and 10 ft deep was used. Sampling tubes were placed at one-foot intervals of depth beginning one foot below the surface of the stone. Primary settled sewage, obtained from a city sewage treatment plant, was applied at hydraulic loading rates varying from 10 to 35 mgd/acre with recirculation rates varying from 1:3 to 1:1.5.

Each hydraulic loading rate was investigated for two 6-week periods, one during the summer months and one during the winter. When the hydraulic loading ranged between 10 and 30 mgd/acre no change was noticed in the percentage reduction of BOD taken from the same depth and during the same season. However, when the hydraulic loading was increased beyond 30 mgd/acre a decrease in efficiency was apparent.

It was observed that during the winter months 50 per cent of the relative removable BOD was accomplished

by the first 2 ft of the filter and 75 per cent removed in the first 4 ft at hydraulic loading rates ranging from 15 to 25 mgd/acre. During the summer months 50 per cent of the relative removable BOD was accomplished in the first foot and 75 per cent in the top 2½ feet.

It was also observed that as the depth increased beyond 6 ft, temperature played a less important part.

A comparison of filter efficiencies when loaded with raw and primary settled sewage was reported by Hall (36). Two identical filters, 3 ft in diameter and 6 ft deep, were utilized. Raw sewage from the Cydna Sewage Purification Works, Johannesburg, South Africa, was piped to a flow diversion box where the flow was divided, a portion going to one filter and a portion to a settling tank of the Dortmund type. After settling for approximately 2¼ hr the effluent was applied to the second filter.

It was concluded from this study that settled sewage is more easily oxidized than raw or unsettled sewage and that improving the degree of treatment afforded by the primary units will permit an increase in the hydraulic and organic loads applied to the filter without reducing the over-all degree of treatment.

The performance of 6-ft deep biological filters built below ground level at the Sewage Treatment Works in Springs, South Africa, was described by Westhof (127). While construction of the filter units below ground level permitted gravity flow throughout the plant, some question existed as to what effect the location would have on filter ventilation and efficiency. One experimental unit, constructed in 1951, has been in continuous operation without deleterious effects. Its effectiveness influenced the construction of five additional units in similar locations.

It was found that closing of the vent stacks produced no deterioration in the filter effluent and they were omitted in the later units. It was concluded that the filter obtains sufficient air from the top for efficient operation and that the air travels in the direction of the effluent flow.

Waller and Ingols (125) found the addition of sodium nitrate to flooded filters of the Atlanta, Georgia, Sewage Treatment Plant provided an economical means of odor control. Hydrogen sulfide emanating from the filters which were flooded weekly in an effort to control filter flies resulted in an increase in the number of complaints reaching the plant. Chlorine and ortho-dichlorobenzene, an insecticide, were tried as a means of controlling the filter flies without flooding but the cost exceeded $100 per day. When flooding was used and sufficient sodium nitrate added to provide the necessary oxygen during the inundation, both problems were solved at a cost of only $30 per day.

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Activated Sludge

Morgan and Bewtra (78) called attention to the need for a standard method for the evaluation of oxygen absorption characteristics of various air diffusion devices and recommended that diffusers be tested for their oxygenation rate in a full-size tank with clear tap water at 20°C and zero dis-

solved oxygen. Dreier (21) pointed out the value of surface aeration. Instead of diffusing air in the smallest bubbles over relatively wide areas of tank bottom, by the use of media with very small interstices, he advocates narrow air dispersion bands which produce turbulence that breaks large bubbles into small ones and prevents the coalescence of the small bubbles. Accurately reamed short tube orifices, ranging from 1/8 to 3/8 in. in diameter, yield air velocities between 100 and 300 fps and the mixture of air bubbles and liquor comprising an air lift, streams rapidly upward 12 to 18 in. where it passes through a critical velocity. There, a sudden change in energy causes the bubbles to shear. This immediate region becomes charged with minute bubbles averaging as small as those discharged from media with a permeability of 40. The diffusers can disperse 4 to 18 cfm of air with low head loss. No air filters are required.

A 6-ft aeration unit was tested by Hurwitz (40) in a tank 28 ft square and 13.5 ft deep with 3-ft, 45° bottom fillets. The unit was operated with the lip of the cone 1/2 in., 2 in., and 4 in. above the water surface at speeds of 25 to 39 rpm. The oxygen absorption rates were measured by adding sodium sulfite with cobalt catalyst in slight excess to a tank to deaerate the water. In tap water, oxygen absorption values up to 23.5 lb/hr, depending on the speed of the cone, were obtained at a gross power consumption of 0.36 kwhr.

Based on simplified theoretical considerations, Fischerstrom (27) has developed a calculable system using dispersed air at shallow depths. This is an idealized spiral flow system consisting of a low head aerator resting on a partition wall with openings at top and bottom. Cross walls support the aerators, making a "flow controlled aerating basin." The research work and full-scale operation of activated sludge plants show that it is quite possible to aerate water to produce an extremely high oxygenation rate economically, by introducing air at low pressure and correspondingly greater rates through perforated pipe.

Oxygen transfer and power cost of turbine aerators installation of the West Virginia Pulp and Paper Company's Covington, Virginia, activated sludge plant are reported by Laws and Burns (58). With the larger orifices of the spargers, scaling was not a problem. Although some scaling was observed during the two months' test period, the optimum submergence of the top impeller was found to be 13 in. The over-all oxygen transfer efficiency was 18.5 per cent. The turbines dissolved oxygen at the rate of 2.54 lb/hr/hp. The increased aeration efficiency permitted a higher BOD loading than was possible with the former type of air diffusion equipment. A power saving of over 40 per cent of the previous consumption for aeration was achieved. The maintenance requirement of the aerators was low.

A contribution to the theory of aeration, effect of temperature on aeration, oxygenation capacity of brush aeration in a small tank is made by Pasveer (89). Interesting concepts are also advanced regarding the rate of transport of oxygen beginning with its introduction into the liquid and ending with the penetration into the floc. Results are given of a brush aeration plant giving complete purification with a BOD loading up to 275 lb/day/1,000 cu ft with an average aeration period of 1 1/2 hr, as a result of increasing the oxygenation capacity and the degree of turbulence.

McNicholas and Tench (75) reviewed the experimental work carried on at Manchester, England, with different types of mechanical aeration units. Acceptable effluents were produced with about two hours' aeration by increasing the rate of oxygen supply per unit volume of aeration tank. Intensification of aeration did not result in the dispersion of the floc and permitted

the maintenance of larger quantities of activated sludge in good condition.

Tench (117) developed an equation which describes the relationship between activated sludge activity and concentration.

Shatto (102) used an aerobic digestion system, followed by filtration of the settled effluent through an automatic diatomite water filter, to provide a high degree of purification at low cost for domestic sewage from 65 to 70 persons.

A new type of filter media was investigated by Schaffer *et al.* (99). Four plastic films, 1 to 3 mil in thickness, were tested at a pressure of 12 in. of water, using commercial oxygen at an average gas pressure of about one atmosphere. The oxygen transfer to settled sewage ranged from 75 to 120 ml/100 sq in./24 hr/atm. As the films were fragile, they required close control of pressure and protection from mechanical injury before and after immersion. No film degradation by biological action was detectable after 60 days' immersion.

Sawyer (96) has very effectively described various modifications of the activated sludge process and has presented data to show what these have accomplished. One of these modifications, completely mixed activated sludge, has been discussed by McKinney (74) and Kalinske (48). McKinney pointed out some of the applications of the process and concluded that, for small plants, total oxidation units with a low food/microorganism ratio, which results in small sludge formation, are best economically. For large plants, economies favor units in which a high food/microorganism ratio produces a large volume of sludge. Kalinske reported that completely mixed units can handle loadings 4 to 6 times greater than conventional plants. For example, daily domestic sewage loadings up to 300 lb per 1,000 cu ft of aerator capacity or up to 1.5 lb BOD per pound of aeration tank solids are possible. It is important to have rapid separation of the solids from the liquid to avoid depletion of oxygen in the liquid portion. Busch and Myrick (13) have investigated the limitations of the so-called complete oxidation process in laboratory scale apparatus. They found that total oxidation is neither theoretically nor practically attainable unless effluent carry-over of solids is sufficient for balance. No food-population equilibrium was reached in batch or continuous systems after operation at one organic loading for as long as 103 days. For systems of the type studied, the authors believe that extrapolation of batch unit data to continuous plant design is not practical.

Pilot-plant studies in Kassel, Germany, by Kehr and von der Emde (54) showed that satisfactory biological treatment can be obtained with very short aeration periods. Using Brandol 60 diffuser tubes, Kessener brushes, or the Inka system of aeration, 80 to 90 per cent removal of BOD (raw sewage 60 to 160 mg/l) could be obtained with a hydraulic loading of 300 gpd/cu ft and about 36 min aeration. Assuming 20-per cent removal of BOD by primary sedimentation, an over-all BOD removal of 75 per cent could be obtained with a 15-min aeration period. The authors also described the operation of the Kessener brush aeration plant at Detmold, which treats sewage and plywood wastes having a population equivalent of 100,000. With an aeration period of 35 to 40 min, about 85-per cent removal of BOD was obtained in the biological section of the plant from a settled sewage containing 200 mg/l BOD. Sewage added continuously over three-fourths of the length of the aerators led to a high concentration of sludge in the aeration tanks (6,000 to 12,000 mg/l). The return sludge volume was 30 per cent of the sewage flow and the suspended solids were 20,000 to 30,000 mg/l.

Eckenfelder (23) found that the ini-

tial removal of BOD in the bio-oxidation process is governed primarily by the nature of the organic substrate and the condition and concentration of the activated sludge. Further BOD removal rates depend on the concentration of BOD to be removed, the rate being independent of concentration at high BOD levels but dependent on concentration at low levels. He has developed mathematical formulas to describe these phenomena.

Bringmann (10) has discussed the reaction whereby nitrates and nitrites in a sludge are reduced to produce gaseous nitrogen. He has shown that, by mixing a well nitrified activated sludge with sewage under controlled conditions of oxidation-reduction (−230 mv), organic matter in the sewage is oxidized as the nitrate-nitrite nitrogen is reduced. The mixture is then aerated for a short period to oxidize the remaining oxidizable organic matter, especially those substances causing odor. Bringmann reported BOD removals from the sewage of 85 to 90 per cent.

More and more substances, once thought to be toxic to activated sludge organisms, have been found amenable to treatment. Malaney (67) was able to acclimate activated sludge to utilize aniline as a sole source of carbon and energy. This acclimatized sludge was also able to oxidize a wide variety of chemical compounds related in chemical structure to aniline. Rogovskaya and Lazareva (94) found that many organisms, widely distributed in water and soils, can be used to make activated sludge useful in the purification of phenol-free gas wastes and wastes from fatty acid synthesis and rubber reclaiming. These organisms could also purify wastes containing phenol and resorcinol as well as domestic sewage. The sludges investigated did not differ widely in microflora but showed wide diversity in metabolic types among heterotrophic organisms. This agrees with the rapid adaptation of sludges to widely diverse wastes. All isolated bacteria were capsulated and capable of forming active sludge flakes. Mixed cultures served better than pure cultures. Bacteria which decompose phenol comprised 45 to 90 per cent of the microflora in the sludges and adaptation to phenol can increase the percentage. Ludzack and Ettinger (63) collected data on the aerobic biochemical stabilization of many organic compounds, in an attempt to clarify the relationship between chemical structure and microbiological assimilation. Emphasis was placed primarily on investigations in which the microbiota was acclimated to the particular test chemical prior to oxidation tests. The data include information on activated sludge and other aerobic biological processes. Rosenthal and O'Brien (95) and Ludzack (62) have given detailed information about making laboratory scale activated sludge units.

Husmann and Malz (43) reported that, based on laboratory scale experiments at temperatures ranging from 20 to 55°C, activated sludge had maximum activity at 30°C. The ammonia content of the effluent was appreciably greater at the higher temperatures than in the mesophilic range. The isolation of the floc-forming organism, *Zooglea ramigera* was described by Dugan and Lundgren (22), who compared the growth of the organism in complex and chemically defined media. Growth in chemically defined media was greatly stimulated by nucleotides and purine and pyrimidine combinations. Total cellular nitrogen was used as a measure of growth. The description of the organism isolated and identified as *Zooglea ramigera* agrees with those found in the literature.

Sludge bulking by the discharge of waste into a municipal sewage treatment plant with a maximum cyanide concentration of 8.6 mg/l and a copper concentration of 3.6 mg/l as received at the plant is reported (6).

Bulking of activated sludge treating

wood pulping wastes is reported by Tkachenko and Drublyanets (118). The bulking due to *Sphaerotilus* is attributed to the sugar content which was 1,000 to 1,500 mg/l and to the acidity of the waste. Dilution of the wastewater was effective in controlling bulking.

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Disinfection

McKee *et al.* (73) have reported the results of an intensive research study designed to determine the chemical reactions involved and the colicidal effects produced in the treatment of settled sewage with the halogens: chlorine, bromine, and iodine. Fluorine was not considered due to its extreme reactivity.

The authors present a comprehensive discussion of the chemistry of halogens and a brief survey of the analytical methods commonly used. In their tests, a modification of the standard acid starch-iodide method was employed in order to take into account the high reactivity of iodine with organics in sewage.

Sufficient graphs are included dealing with the relationships between halogen dosage, contact time, colicidal efficiency, and halogen residual.

The results of their research indicate chlorine, bromine, and iodine residuals are equally effective colicides on a molecular basis. Because more iodine and bromine are used in satisfying halogen demand, chlorine is superior on a dosage basis. Iodine is superior once the halogen demand has been satisfied. However, on a weight basis, chlorine is more superior than the others (8 mg/l of chlorine will yield coliform kills comparable to that of 45 mg/l of bromine and iodine) and chlorine is less costly. Thus, the authors conclude that bromine and iodine should be excluded from practical consideration in sewage disinfection.

Sherbeck (103) has shown in an operations report that split chlorination is a more effective colicidal procedure than single-shot chlorination in sewage treatment based on samples collected over an observation period of four years.

Kelly and Sanderson (55) have extended previous work to a study of the effects of combined residual chlorine on the two strains of virus which had originally been isolated from chlorinated sewage. The research involved two types of observations: (*a*) comparison of the rates of inactivation of the two strains of enterovirus at different pH levels by one combined residual chlorine concentration, and (*b*) estimates of the times and concentrations of combined residual chlorine required for greater than 99.7-per cent inactivation of the resistant strains (this represented the limit of detectability of the virus in most suspensions). Plaque counts were made in bottle cultures of Hela or monkey-kidney epithelial cells. The results show that at 25° C and a pH value of 7.0, a concentration of at least 9 mg/l was necessary for polio virus inactivation with 30 min contact, 6 mg/l with 1 hr contact, and 0.5 mg/l required a contact period of more than 7 hr. For the resistant strains, an increase in contact period was a better disinfecting procedure than was an increase in concentration. Higher pH values enhanced the rate of inactivation. The authors conclude that the minimum concentrations and contact periods for the inactivation of polio virus indicate that the current recommendations for sewage treatment may not disinfect viruses. Disinfection is defined as "destruction of all pathogens," and therefore present-day standards are not adequate.

Lowe *et al.* (61) have reported on the use of gamma radiation for disin-

fection. Samples of double-distilled water and autoclaved sewage were inoculated with appreciable doses of *B. subtilis*, *M. smegmatis*, *S. aureus*, *E. coli*, and *T-3 coli phage* and exposed to gamma radiation from a 1.1-kilocurie source of Co^{60}. Samples of settled sewage and settled sludge were similarly irradiated. All of the test organisms, when suspended in distilled water and in sterilized sewage, were destroyed by gamma radiation. The dosage for complete kill was high, ranging from 2.0×10^6 r for *B. subtilis* spores to 7.5×10^4 r for *T-3 coli phage* when suspended in distilled water. The samples of settled sewage and sewage sludge required 5.0×10^6 r and 2.0×10^6 r for 100-per cent kill, respectively. Dosages up to 7×10^4 r resulted in kills up to 90 per cent in water, sewage, and sludge with the exception of *B. subtilis*.

An aspect of disinfection which possibly could have far-reaching implications has been presented in a joint committee report (16) dealing with the supply, inventories, and use of chlorine in 51 sewage and 151 water treatment plants out of a total of 191 U. S. cities selected to represent population sizes in five geographic sections. The relatively small number of sewage treatment plants using chlorine is indicated by the number of returns. A "critical inventory" represents the number of chlorine containers not in use equal to the number normally in service.

A recommended "working inventory" represents a critical inventory plus a reserve amount equal to the amount consumed during a period equal to normal delivery time plus a 15-day emergency supply. The average working inventories at water and sewage plants were 26 and 22 days, respectively. Two-thirds of the water plants and one-half of the sewage plants were maintaining the recommended working inventory. Although delays in delivery were infrequent, the committee recommended that management evaluate its supply and operating procedures to determine if they are adequate for emergencies.

Sludge Digestion

Theory and Mechanism

The basic biochemical reactions involved in the destruction of carbohydrates, lipids, and organic nitrogen, and in the formation of methane, were reviewed by Simpson (105). Control of these processes during anaerobic digestion of sewage sludge, and the significance of total acid concentration and of individual volatile acids in digesting sewage were studied by several authors. Etzel and Pohland (26) in experiments in the thermophilic range concluded that the main mechanism of methane production seems to involve propionic and acetic acids to a greater degree than other volatile acids. They postulate that gas production lags when acetic is no longer being decomposed to methane and CO_2 as rapidly as it is formed; and that an observed drop in propionic results from its conversion to acetic acid. Evidence is mounting that when volatile acids rise above the available associable cations, free volatile acids are produced. These destroy the buffering action of sludge and lead to a rapid decrease in gas production and pH. Preliminary studies showed that a digester loading of 0.1 lb/day/cu ft digester capacity gave rise to more than 2,000 mg/l in the mesophilic range of temperatures. Liubimov and Kagan (59) found little difference in the composition and quantity of acids in the alkaline stage of digestion. Working with a mixture of primary sludge and waste activated sludge digesting at mesophilic temperatures, they observed, however, that the acid fermentation stage produces propionic, butyric, isovaleric, acetic, and formic acids. After alkaline digestion is established, the first three of these acids disappear and caproic acid appears. Grumbling and Sawyer (34) noted that there is yet no way to "ap-

ply the brakes'' to activity of the acid formers to allow methane-forming organisms to catch up. Experimental digesters in distress did not show pH changes as gas production declined until volatile acids reached 1,000 mg/l, as acetic acid, or more, depending on the buffering capacity of the unit. The factors which these authors list as responsible for the inactivation of methane organisms include one or more of the following: (*a*) the destruction or impairment of structural cell organization, (*b*) an interference with the energy-yielding metabolism of the cell, (*c*) an interference with biosynthesis or growth of the cell, and (*d*) mechanical injury.

Washed suspensions of *M. omelianskii* were found by Johns and Barker (47) to be capable of converting ethanol to acetaldehyde anaerobically or, in the absence of CO_2, to acetic acid and hydrogen. An atmosphere of hydrogen, however, inhibits oxidation of ethanol.

O'Neill (86) found that one per cent of copper, on a dry solids basis, caused an appreciable reduction in gas yields although not as profound an effect as produced by zinc. Some acclimatization of organisms to copper was observed.

Successful application of anaerobic digestion to raw distillery wastes when the waste was enriched with methane bacteria, isolated from a continuous methane culture, and digested for a period of two to three weeks, was reported by Ghose and Rao (30). Addition of excess carbonate produced a clear effluent after 14 days, but its oxygen demand was not different than that of the waste digested without added carbonate. Laboratory tests by Madera (65) indicate that TNT wastes can be purified anaerobically. He further reported that a combination of anaerobic and aerobic methods has been successfully used for wastewaters from citric acid production.

New Developments

Grune (35) applied gas chromatography to the analysis of digester gas. In his experiment, C^{14} is used to distinguish between acid cleavage and methane production processes.

Maintenance and Operation

The conditions of operation and maintenance which are optimum for anaerobic digestion of sewage were summarized by Simpson (105). Best results occur when raw sludge is fresh, high in solids content, and contains no critical amounts of toxic materials. Such sludge should be fed to the digester frequently or continuously, the digester contents mixed, and a constant temperature maintained. Scum control is also an important factor. Scott (101) described some of the difficulties in such control in Toronto. Fixed-cover tanks were found to develop a very solid scum at a rate of six inches per month. A two-year accumulation of 12 to 18 ft of scum endangered the structure itself. Gas recirculation proved unsuccessful. By applying air at the rate of 600 cfm for 24 to 48 hr the scum softened enough for drawoff but rehardened in a few hours. Scum in the amount of 5,250 cu yd was removed through 2-ft diam manholes. In newer primary tanks, 4 ft of scum is now removed every 24 months. The general effectiveness of agitation in keeping down scum by vigorous agitation of tank contents is attested by Estrada (25). The method to be used is largely determined by economics, based on the cost of agitation as well as on reduced digester size. He concludes that (*a*) sufficient data are available to demonstrate the value of gas recirculation and vigorous agitation, and (*b*) mechanical agitation will not increase the rate of digestion although high loadings are possible if the sludge is concentrated. On the basis of 16 months of operating digesters converted to high-rate, Nash and Chasick

(80) report new high loading rates of 490 lb/day/1,000 cu ft, on the basis of total solids, or 380 lb/day/1,000 cu ft, on the basis of volatile solids. Under this loading a minimum digestion time of 12 days seems possible. The digesting sludge produced 8.1 cu ft of gas per pound of volatile added, and yielded a digested sludge concentrated to 11- to 12-per cent solids having 60.5-per cent volatile matter. Gas yields and loadings were reported by Kiess (56) for some 100 plants in Germany. The heaviest loaded plant handles 2 kg organic matter/day/cu m; the average gas yield of all plants is 0.34 cu m/day/cu m digester capacity.

For high-rate plants Sawyer and Grumbling (97) conclude that:

1. Concepts of unimolecular and first-order reactions can be applied to predict the increase in organic loading with sludge concentration.
2. Mixing becomes a problem when total solids in mixed liquor approaches 6 per cent.
3. Total solids in mixed liquor is a function of such solids in the raw sludge; and the detention time.
4. It is impractical to concentrate feed sludge to more than 8 per cent unless fixed solids in raw sludge is less than 35 per cent or volatile matter is greater than 65 per cent.

Hindin and Dunstan (39) conclude from laboratory studies that a single-stage anaerobic digester can treat raw sludge efficiently at a maximum loading of 0.075 to 0.10 lb volatile matter/day/cu ft if the digestion period is not less than 30 days. Volatile acids, the authors conclude, is the best measure of the condition of a digester, with 2,000 mg/l as acetic acid being the maximum permissible for efficient operation.

The effect of sludge digestion on TB bacteria was observed by Müller (79). In Germany raw sewage was found to contain as many as 50 to 100 organisms per liter. Only with thorough digestion in heated digesters (85°F) were the organisms eliminated. Samples from unheated digesters were 50-per cent positive, and sludge after as long as 30 days drying showed 44-per cent positive samples. Heat treating of sludge at 140°F is considered necessary if sludge is to be used for agricultural land.

Design

Studies by Estrada (25) led to the conclusion that there are not yet enough data to fix criteria for the design of high-rate digesters but that their demonstrated effectiveness justifies the adoption of conservative interim criteria in order to take some advantage of the savings which can result from their use.

Langford (57) discussed the digester volume requirements including the capacity for sludge storage, supernatant, and actively digesting liquors. Operating results from nine plants equipped with gas recirculation digesters are given. Digester volumes can be reduced as consideration is given to practical control of digester heating, raw feed concentration, controlled supernatant removal, and a flexible method of mixing allowing for bottom solids classification.

From a theoretical consideration of the interaction between substrate and organisms in the biological stabilization of industrial wastes, Stewart *et al.* (111) developed a rational approach to the design of continuous flow anaerobic systems of waste treatment. Constants in mathematical expressions which describe the kinetics of biological processes were derived from pilot plant experiments. The resulting equations are valid for the design and operation of anaerobic fermentation processes dealing with the several types of organic industrial wastes studied.

A new plant described by Stöckicht (112) is designed to heat fresh sludge by low pressure steam introduced diagonally at the surface.

After 15 days' digestion at 33°C the sludge is pasteurized at 75°C for 30 min for use on irrigated fields.

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Sludge Disposal and Utilization

Sludge Concentration and Conditioning

Budd (12) has reviewed the methods currently employed to thicken raw sludges. Results of continuous gravity-type thickening are discussed in relation to the sludge volume ratio. The attempts at flotation thickening, with emphasis on the Laboon process are described and results of recent work in centrifuging and vibration are noted. Pilot-plant experiments on thickening of raw sludge at the Back River Sewage Treatment Plant, City of Baltimore, were conducted by Keefer (53). The raw sludge was a mixture of primary, activated, and trickling filter sludges whose feed concentration to the experimental thickening tank was varied by means of primary tank effluent. The variables studied were influent solids loading, and depth of sludge blanket at a detention time of 1.5 hr and a surface settling rate of 790 gpd/sq ft. Four groups of tests were made varying from an average influent suspended solids concentration of 1,510 mg/l or 9.92 lb/day/sq ft to 3,069 mg/l or 20.1 lb/day/sq ft. The highest sludge concentration of 8.5-per cent solids was obtained at a loading of 14.0 to 14.5 lb/day/sq ft. Decreasing or increasing this loading concentration decreased the sludge solids concentration. The depth of the sludge blanket greatly affected the sludge concentration. In general, the concentration varied inversely with the depth of sludge blanket between 1 and 3 ft. It is expected that by increasing the sludge concentration from the present 4.6 per cent to the attainable 8.5 per cent solids, a savings of approximately $1,270 per month can be realized. Glace (31) has shown the financial advantages of a gravity thickener at the Haw River Sewage Treatment Plant in Burlington, North Carolina. The plant is designed for 6 mgd, and will include high-rate trickling filters, chemical precipitation, sludge thickening, and sludge digestion. Calculations indicated that thickening to 8-per cent solids will reduce the sludge quantities fed to the digester from 6,750 to 2,440 cfd. This will represent a savings of $197,300 in the construction costs of the digesters or approximately 11.3 per cent of the total plant cost.

The feasibility of filtering and disposing of raw sludge was reported by Spaeder (110). Citing costs from a number of installations utilizing vacuum filtration of raw sludge, it was concluded that savings as high as $4.00 to $7.00 per capita design may be realized and that operating costs compare favorably with digested sludge dewatering. Since proper chemical conditioning to pH 10 to 11 can produce a bacterial count in raw sludge equal to that obtained from digested sludges, there should be no disposal problems associated with health or odor considerations. Davidson (19) has described the sludge handling practices at Ogden, Utah. The plant is designed for a population equivalent of 314,000 of which more than 50 per cent is industrial waste. Primary sludge is dewatered by a continuous-belt vacuum filter using a synthetic medium. With 1.5-per cent $FeCl_3$ and 7.5-per cent CaO dosage, filtration rates have averaged 10 lb/hr/sq ft with a cake moisture of 70 per cent. The

dewatered sludge is hauled to a 68-acre site for sanitary land fill disposal. Total disposal costs are $15 per ton dry solids of which $9 are for conditioning chemicals.

Keefer (51) has experimented with aluminum chlorohydrate as a conditioning agent. A primary-activated digested sludge was elutriated and filtered through a Buchner funnel. The results of comparative studies of aluminum chlorohydrate and ferric chloride indicated that aluminum chlorohydrate gave a greater cake yield but higher cake moisture than ferric chloride with a similar amount of conditioning agent. Filtering 15 min or 30 min after the addition of aluminum chlorohydrate still resulted in higher cake yields as compared with filtering immediately after conditioning with ferric chloride, but the percentage increases were less with increased time of delay. Brown (11) has discussed the operating experience of vacuum filtration at New Rochelle, New York. Digested sludge is concentrated, conditioned with lime and ferric chloride, and filtered through a coil spring filter. The costs of filtering average $15.66 per ton dry solids, and incineration costs are $12.98. The basic factors affecting conditioning and filtration in relation to the operational results obtained are discussed. Keefer (52) has concluded that accurate measurements of sludge concentration can be obtained by use of a radioactive detector unit. Tests were conducted at the Back River Sewage Treatment Plant utilizing a cesium-137 source. The principle of detection is associated with the degree of interception of the radiation source as a function of the solids content of the sludge. The current received by the detector is amplified and the receiving instrument is calibrated to indicate the per cent sludge solids. Comparisons of this method with the procedure given in "Standard Methods" gave differences of less than 0.35 per cent 50 per cent of the time, and 0.137 per cent 10 per cent of the time. If a continuous recorder is used in conjunction with the density analyzer, it is possible to obtain a summary record of a large number of analyses without the delay associated with the "Standard Methods" procedure.

There were two papers dealing with the flow of sewage sludges in pipelines. Behn (7) has given an excellent review of the subject and has developed the equations which are applicable to the results obtained from capillary viscometric and rotational viscometric studies. The parameters necessary to derive the relationship between shear rate and shear stress in non-Newtonian sludge are described. Since mathematical models depicting non-Newtonian flow of the Bingham plastic and pseudoplastic types, which are applicable to sewage sludges, are available, the flow parameters required can be identified and determined by means of viscometry. This information, relating shear stress to shear rate, will allow estimates of pressure drops in pipelines. Sirman (106) has described the experimental procedure and technique in employing a capillary viscometer for determination of the shear stress and the pressure drop. The necessary plots to obtain the apparent Reynolds Number and the flow-behavior indexes are given. Results indicate that a 2.8-per cent digested sludge has Newtonian properties at laminar flow, its deviation from water being a function solely of viscosity. With increasing solids concentration, the deviation from Newtonian flow increases with decreasing flow rates.

Sludge Disposal and Utilization

A concise description of the equipment, operating characteristics, and costs of wet oxidation plants to be constructed in Chicago, Illinois, and Wheeling, West Virginia, have been published (3), and Hurwitz and Dundas (41) have described the criteria

and results of pilot-plant studies which will be utilized to design the full-scale plant for the Metropolitan Sanitary District of Greater Chicago. The full-scale plant which will handle 200 tons of dry solids per day will cost 13 million dollars. It will consist of 4 individual units with a capacity of 50 tons dry solids at 3-per cent solids concentration. Each unit will consist of an air compressor driven by a 2,250-hp motor with a capacity for compressing 4,800 cfm of free air to 1,850 psi. The reactors will be 61 ft high, weigh 160 tons, and be designed for a pressure of 1,800 psi at 600°F. Pilot-plant studies have shown that the degree of sludge degradation, as measured by the COD is a function of temperature and does not vary appreciably with solids concentration. However, the power costs are a function of solids concentration. A 4.4-per cent sludge is the break even point; a 2-per cent will cost $2.50 per ton dry solids, while a 6-per cent sludge may yield $0.65 per ton dry solids as recoverable heat energy.

Martin and Bryden (71) discussed the principles and application of the atomized suspension technique to sludge disposal. Pilot-plant studies were carried out on a raw sludge having a solids content of 4.5 to 6 per cent. The sludge is comminuted and preconcentrated in a cyclone evaporator to 11-per cent solids. It is then fed at a pressure of 30 psi to atomizing nozzles, thence to the reactor operated at a wall temperature of 1,400 to 1,450°F. The evolved gases and steams are condensed and vented to a furnace and the solid particles in the lower portion of the reactor are separated from their conveying media in a cyclone. A study of the heat balance indicated that of a total heat supply of 970,000 Btu/hr at a reactor feed rate of 750 lb/hr, 36 per cent useful work was done; 46 per cent of the supply was contained in the flue gases leaving. A $35,000 atomized suspension technique unit designed to handle sewage sludge from a population of 12,000 has been installed for Beaconsfield, Quebec (5). Concentrated primary sludge is atomized into the reactor held at 1,400°F at the top and 1,000°F at the bottom. Air is introduced to oxidize the organic matter; the resulting N_2 and CO_2 gases are vented to the atmosphere, and the separated ash is discharged to the river.

Nickerson (81) has discussed the costs of sludge treatment and disposal at Waterbury, Conn.; Camden, N. J.; and Schenectady, N. Y. The first two handle raw primary sludge while the third handles digested primary. Each plant dewaters by means of drum-type vacuum filters followed by flash drying and/or incineration. The 1957 disposal costs at Waterbury were $26.14 per ton dry solids of which $14.34 was for wages, chemicals, power, and supplies; and $11.80 was for annual debt service on equipment and facilities. The operating costs at Camden were $17.05 per ton dry solids, of which labor, chemicals, and burning were $5.08, $6.48, and $7.35 per ton, respectively. Schenectady disposes of its primary digested sludge as a soil conditioner under the trade name, Orgro, at $1.00 for a 65 lb bag. Considering the revenues obtained from the sale of the Orgro, $7,315 in 1958, the net operating costs were $5.04 per ton. Although the sale of Orgro produces a net profit, the necessity of incinerating sludge in the winter results in a net cost for the total yearly operation.

Sawyer and Kahn (98) conducted laboratory studies on temperature requirements for odor destruction during incineration. Primary sludge, a mixture of primary and activated, and sludges from anaerobic flotation were conditioned, burned in a Lindberg furnace, and submitted to a test panel for odor evaluation. The results indicated that although the temperature required for destruction of odors varied with the type of sludge and conditioning, most sludges required a temperature of 1,300°F for deodorization. At 1,250°F

the odors were appreciable and at 1,200°F the odors were severe.

Keefer (50) has described a new granulating process designed to reduce the excessive amount of fines in heat-dried sludge. The process consists of compaction by passing the sludge through two steel cylinders rotating in opposite directions while subjecting the sludge to a pressure of 150,000 psi. The sludge sheet is fragmented and fed into a granulating mill equipped with two rolls, each 9 in. in diameter and 6 in. long. The space between the rollers was adjustable so that the size of the granulated sludge could be varied. The granulated sludge is then passed through vibrating screens for size segregation. This process has significantly reduced the fines and with proper screen selection, the amount of oversize particles can be greatly reduced.

The agricultural disposal of sludge as practiced by the City of Nottingham, England, was discussed by Stone (114). The basis for final sludge disposal is to consider the land as a medium for final aerobic digestion with a view to physically improving and chemically enriching the soil. In order to incorporate sludge application with crop rotation and production, the rate of sludge addition should not exceed the rate of its oxidation or removal in the soil, nor should the application time be large in relation to the time engaged in crop production. Based on a loss of 3,000 to 6,000 lb sludge organic matter per yr per acre, equilibrium conditions would apply if 200,000 gal of 5-per cent digested sludge were applied per acre every 10 yr or approximately 100,000 lb dry solids, or 50,000 lb organic solids. These loading factors would require 520 acres to dispose of sludge from a population of 125,000 and total costs, including land purchase, facilities, and debit amortization would approximate $15 per ton dry solids. Operating experiences and experiments on 225 acres used primarily for sugar beet production for the past 4 yr are given. Sludge application has increased the yield of sugar beets but with a loss in sugar content. Difficulties have been experienced with manganese deficiencies at 35- to 40-per cent sludge application, and at 70-per cent, production failed. Jeffrey (45) studied the effect of sludge depth on the dewatering rates of digested sludges in "laboratory lagoons." The results indicated that after 20 days the drainage rate is proportional to depth. Although the drainage in the first three weeks is erratic, it represents as much as 46 per cent of the total discharge for 200 days. Tomato plants were employed to measure the effect of transpiration. Using sludge of 8-per cent solids at a loading of 2.4 lb dry solids per sq ft per 30 days of lagoon operation, during a 60-wk period it was found that drainage reduced the moisture content to 74 per cent, evaporation and drainage to about 60 per cent, and evaporation, drainage, and transpiration to less than 50 per cent. Based on these studies, a procedure for calculating lagoon dimension is given.

Digested sludge from the San Diego treatment plant is being utilized for top soil improvement in the Mission Bay recreational area (82). Previously, sludge was sold as a fertilizer with a net cost of approximately $38 per ton dried sludge for the years 1951 to 1956. In addition, large quantities of sludge from the elutriator were being discharged into the bay. In an effort to dispose of the sludge at low cost with a net benefit to the City, the program of hauling and applying sludge to dredged park lands was pursued. With loadings up to 600 tons dry solids per acre, the present developable land can absorb the digested sludge output for the next 20 yr. Hauling charges are based on volume at a cost of 0.0019 per gallon which is equivalent to $9 per ton at 5-per cent solids. The average cost for disposal during 1956 to 1959 has averaged $12.77 per ton sol-

ids. In addition to the benefits to the land, the conditions in the bay have been greatly improved and there has been a corresponding decrease in chlorine demand of the effluent.

Research in the amino acid content and transformations in sewage sludges is continuing in the India Institute of Science (116). Examination of raw sewage, primary sludge, alum sludge, septic tank sludge, activated sludge, and cow dung indicated that all the essential amino acids were present except cystine in septic tank sludge. Activated sludge contained the highest amount of each amino acid and a total of 231.3 mg/g sludge. Inactivation of the protozoa in activated sludge greatly decreased the rate and amount of removal of amino acids from the sewage to the sludge.

Composting

Snell (109) has described his observations of composting practices in 17 countries and 34 cities. Operational practices and experiences of windrow composting (Earp-Thomas, Dorr-Oliver, Dano, and T. A. Crane plants) are described. The public health, agricultural, and economic considerations should be included in any assessment of community waste and refuse problems. It is felt that it should be possible to produce compost at a cost of $2 to $4 per ton and to sell it, on the basis of its nitrogen, phosphorus, and potassium values at $8 to $15 per ton, equivalent to an increased crop yield per month of $20 to $40 per ton. Gotaas (33) has discussed in detail the important factors to be considered in the design and planning of refuse composting plants for cities. The unit processes described are refuse receiving, separation and salvaging of scrap, and shredding or pulverizing the refuse preparatory to composting.

The 35 ton pilot composting plant at Norman, Oklahoma, is described by McGauhey (72). The incoming refuse is handpicked for salvagable and uncompostable items, including rags, metals, and cardboard. The material is then processed through two grinders which pulverize and grind to a determined fineness. First-stage composting takes place in a 3-tiered cell. The partially composted material is ground again and conveyed to a second 3-tiered compost cell. A third grinding is followed by screen sieving and bagging. The author feels that composting has "come of age" from the standpoint of engineering and the necessity of communities to seriously consider the process as a legitimate one for solving refuse disposal problems.

Based on 3-yr operating experiences at Sacramento, Golueke (32) concludes that it is an economically and technically feasible method of handling refuse. The process consists of sorting the incoming refuse prior to grinding in a 25-ton hammermill crusher. The material is then conveyed to the composting unit which has a capacity of 90 to 120 tons. Air and water are added along the drum which reaches a temperature of 140°F. The detention time of 1 to 3 days produces a semi-stabilized compost which is reground and stacked in windrows for 14 days with 2 to 3 turnings. The finished product contains 1.25 per cent nitrogen, 0.4 per cent P_2O_5, and 0.3 per cent K_2O and can be produced for less than $3.25 per ton.

Israel (104) has embarked on a full-scale garbage composting program in an effort to produce sorely needed organic fertilizers. Tel Aviv is designing a 500-ton capacity, fully mechanized plant at a cost of $1,100,000 while Haifa has recently completed a 60-ton plant. Composting the 880,000 cu m of garbage produced annually will make available about 260,000 cu m of compost; a supply sufficient for 25 per cent of the country's needs. The plants are being subsidized by the municipalities and the selling price of $2.80 to $5.00 per cu m for the compost should result in a profitable enterprise for

private interests. Davies (20) has briefly discussed two important considerations in adding sewage sludge to refuse for composting. One is the problem of insuring destruction of pathogens; the other is associated with the transport and moisture content of the sludge. Research results would indicate that a well-designed compost plant can successfully process sewage sludge with refuse if the sludge is thickened to 70- to 75-per cent moisture content. Six to 10 tons per day of sludge, comprised of fermentation of antibiotics, pharmaceutical extracts, and sewage are composted at the Lederle Laboratories, Pearl River, N. Y. (28). Based on pilot-plant studies, a full-scale 150-day shredding and windrow process has been developed. The sludge is mixed with manure and sawdust in the weight percentage ratios of 65:25:10, to give an optimum blend from the standpoint of materials handling. The compost which is used on the grounds and sold locally, represents the most practical method of treatment and disposal of the wastes. Toth (119) has estimated that there is sufficient organic residues available in the State to add one ton to all the cultivated land in New Jersey. The available supply from garbage, sewage, and industry is 1, 0.5, and 0.2 million tons, respectively. The moisture, ash, nitrogen, potassium, and phosphorus content of a large number and variety of industrial organics are given and their utility for land use is discussed. This potential, it is felt, should stimulate industry to sponsor research to evaluate their wastes for agricultural purposes.

Rodale (93) has indicated the importance of the expanding garden market for compost sales. On the basis of its nutrients and soil conditioning properties, compost should attract a greater market than peat. The distribution and sales techniques are cited as important study areas for successful marketing of the product. Olds (84) (85) has presented information on sales of sewage sludge. The practices employed and prices received by numerous cities in the sale of sludge are noted. An increasing demand for the product is predicted and public education and dissemination of knowledge is deemed necessary for the development of the potential market.

The objectives of temperature control in composting are discussed by Snell (108). The composting process is divided into three stages, each with its optimum temperature range. The initial stages associated with breakdown of sugars, require the low temperature, 100 to 110°F; the intermediate stage of protein breakdown requires moderate temperatures, 120 to 140°F, and a final high temperature stage of 140 to 170°F. A temperature of 140°F for 1 hr will destroy most bacterial and protozoan pathogens in addition to weed seeds and fly larvae.

Jann *et al.* (44) have selected pH as a simple, rapid, and accurate method of determination of completion of composting. By defining completion of composting as that stage which will not undergo anaerobic fermentation, the following test was developed. A 5-g sample is placed in a 20- × 150-mm tube filled with water. The tube is incubated at 55°C and the pH of the contents is determined. If the pH is alkaline, at 7.5 after 24 hr, the compost is considered a stable end product.

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Detergents

Malaney *et al.* (68) investigated the removal of anionic surface active agents from domestic sewage by pilot plant treatment devices. The concentration of anionic detergent in raw sewage, over a period of 28 months, averaged 6.4 mg/l, ranging from 0.5 to 11.4 mg/l. The mean removal by sedimentation was 0.3 per cent; by activated sludge 30.2 per cent, and 18.8 per cent by trickling filter.

Hurwitz *et al.* (42), employing data from three plants in Chicago, confirmed previously reported results, that approximately 50 per cent of ABS is removed in the activated sludge process.

Jenkins (46) reported that the 1957–58 average concentration of synthetic detergents in the raw sewage of the Langley Sewage Works in Great Britain was 30.1 mg/l. This concentration was reduced to 20.1 mg/l by sedimentation and to 10.0 and 7.4 mg/l by biological filtration and grass plot treatment, respectively. The humus sludge contained approximately 1-per cent detergent on dry matter basis. Digestion did not seem to destroy the detergent, most of which passed from the sludge to the liquor or the solids associated with the sludge liquor.

The Standing Technical Committee on Synthetic Detergents (77) of Great Britain in its Third Progress Report stated that there has been no significant change in the average concentrations of synthetic detergents in sewage, effluents, and rivers. Domestic use of liquid detergents has increased while that of powdered detergents has remained the same during the past two years.

A large-scale trial of an alternative active material, more readily decomposable biologically, was begun at Luton in 1958. Complete replacement has not been accomplished as yet. The results so far indicate that a greater proportion of the new detergent than of the old product is removed during sewage treatment. The Committee tentatively concluded that substitution by the new detergent would substantially diminish the troubles associated with synthetic detergents.

Hernandez and Bloodgood (38) carried out laboratory studies on the effects of an ABS on sludge digestion. It was concluded that a concentration of added ABS will be reached which will result in disruption of the digestion process. The relationship of ABS to total solids appeared to be the important relationship.

Lynch and Sawyer (64), in a laboratory study, found that surface active agents adversely affected oxygen transfer by bubble aeration and, in general, the interference increased with an increase in surface activity. Presence of salts causing hardness tended to decrease the oxygen transfer beyond that caused by ABS.

Maney and Okun (70), using Aerosol O.T., found that the rate of oxygen transfer was reduced to a minimum at the critical micelle concentration. Increasing the surface active agent beyond this concentration caused a gradual increase in the over-all transfer rate.

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Lagooning

The history, terminology, theory, and actual installations of sewage oxidation lagoons were discussed in a symposium at Kansas City (91). Much attention was given to practical applications in the different climatic conditions. Data controlling design, construction, and operation of sewage lagoons in the Missouri Basin states are summarized in a report by a subcommittee of the Missouri Basin Engineering Health Council (122). Due attention is given to changes in construction and operation as caused by local and climatic conditions, such as: (*a*) evaporation as influenced by temperature and prevalent winds, (*b*) percolation as controlled by silty subsoil, and (*c*) ice cover and its effect on biochemical action. The physical structures, such as inlets, outlets, and piping for circulation, are specifically discussed. van Eck (121) has reviewed stabilization pond literature from the U. S., Australia, Sweden, and other countries. He discusses the functions of algae, bacteria, protozoa, and fungi, in regard to their interrelations. There are many tabulated reports from the various countries. The report is authoritative and inclusive.

The role of algae, bacteria, and other organisms that bring about the stabilization of wastes in lagoon treatment, have been studied by a number of investigators. Pipes and Gotaas (92) report on the possibility of food production from the waste organic material. They used a pure culture of *Chlorella pyrenoidosa*, under closely controlled laboratory conditions. Their apparatus and methods are fully described, and results completely tabulated. A close correlation between the age of the algae (detention period), the soluble BOD, and the organic content, were observed. The removal of the free swimming algae, such as *Chlorella*, from the culture medium is a problem because of their small size. Gaur *et al.* (29) describe an experiment using a filamentous blue-green alga, a species of *Oscillatoria*, which can be more readily removed. They illustrate their apparatus, give types of substrates employed, and the food substances produced. Two types of algae, *Chlorella* and *Scenedesmus*, were used by Witt and Borchardt (129), in studying the removal of nitrogen and phosphorus from sewage plant effluents. The effects of light intensity were observed. The removal of P from the substrate was never complete, but it continued long after the absorption of N had ceased. The removal of P by algae was also studied by Bogan *et al.* (9). Even though under carefully controlled laboratory conditions such a process was found to be functionally sound, under field conditions inability to maintain adequate light intensities gave rise to relatively high treatment

costs. Accordingly, the process was modified to include pretreatment with lime prior to biological removal of P.

A 3-yr study of algae, bacteria, and protozoa in aerobic and anaerobic pond systems has been initiated at Washington State University (126). The waste reducing activities particularly are to be studied, noting especially the limitations of anaerobic conditions. The interrelations of the three types of organisms, as well as the sludge decomposing power of bottom-dwellers, are to be investigated. This is to be a biological and chemical study of fundamental principles.

The possible production of food from waste matter is the main concern of Wilson (128) in his studies of algal decomposition of organic matter in lagoons. The studies are related particularly to facts of photosynthesis, both in a free and a controlled state. Oswald (88) has studied the efficiency of light energy conversion by pure cultures of algae. He found that efficiency increased as temperature, sewage concentration, and carbon dioxide increased. Efficiency decreased with increased light intensity, light exposure time, and detention period. Light availability was of major importance. Over-all efficiency ranged from 8 to 12 per cent, but values of 3.5 to 4.0 per cent appear conservative for design of oxidation ponds.

There are several interesting and valuable reports of operation experiences with oxidation ponds. Claussen (15) has reported on a temporary system treating the sewage of Wallkom and Allanridge in Orange Free State. He describes the system in detail and gives the history of oxidation ponds in South Africa. The results of an experimental study made during early stages are tabulated. Stone (113) has described waste stabilization basins for a desert sewage treatment plant.

Much of the experience has come from colder climates. Kay (49) has reported in detail on lagoons in Manitoba, Canada, including locations, sizes, loading by population, and methods of operation as influenced by the northern climate. The effects of the increasing industrialization of Manitoba are discussed. Copp (18) has reported that in many regions of northern Canada, the silty soil commonly found influences the water depth adversely, so that additional fresh water may have to be added. He also discusses the effects of increased solubility of oxygen at the cold temperatures. An additional report, similar in many respects, comes from Anderegg *et al.* (2).

A well-documented report of two 100-acre lagoons comes from Regina, Canada (4). The City was forced to enlarge its sewage treatment facilities to provide for an expected 1975 population of 120,000. Circumstances led to adoption of lagoons for the treatment of the effluent from the remodeled primary treatment plant.

An extensive test program at El Centro, California, by Maloney *et al.* (69), revealed that the primary cause of the malfunction of sewage stabilization ponds was the whey content of dairy wastes entering the sewer system. The fact that these wastes had an accumulative ill effect was determined. Poor pond performance was indicated by the low concentrations of dissolved oxygen and desirable algae, as well as by the presence of dissolved sulfides and hydrogen sulfide odors. The addition of nitrates increased the tolerance of the ponds to the dairy wastes in the sewage, but not to any large degree.

From Europe comes a description of an aerated lagoon (123). This report describes how concentrated sewages from a village of 1,000, together with the waste of a slaughterhouse and a milk-product plant, is treated in an aerated lagoon laid out in the shape of a flattened circle with an island at the center. The lagoon has a volume of 79,300 gal, is 3 ft deep, and the annular-shaped channel is 12½ ft wide

at the top. A wheel rotating at 75 rpm dips into the sewage, furnishing aeration. The bottom sludge of the lagoon is odorless and is periodically removed.

O'Connor and Eckenfelder (83) have studied the application of the principles of aeration and oxidation to the design of lagoons. Theoretical laboratory and field studies were considered. Equations were developed and applied to aeration in a lagoon, as related to temperature effects and solids accumulation. A typical plan and profile illustrate the considerations and approach to the problems. A design example is given, and data analyzed in the light of equations presented. In Orford's accompanying discussion of the studies (87), he gives a practical application of the ideas and theories developed. He points out some additional problems that arise in actual application, particularly in relation to accumulation and effects of bottom sludge.

Sewage Reuse

The Talbert Water District (120) in Southern California uses the effluent from the Orange County Sanitary District's primary sedimentation plant for irrigation of such crops as have been approved by health officials. Preceding the full-scale installation, irrigation of a model farm of several acres was studied for three years to observe effects on local soil and on subsoil percolation. Strict regulations were adopted in regard to reservoir management, pumping from the treatment plant outfall main, and salt accumulation in the soil. A similar application and study of sewage irrigation at Nottingham, England, is reported by Stone (114). The principal objective was sewage disposal, utilizing the purifying power of the soil. The relation between type of soil and its ability to absorb the sewage and destroy the organic material was studied. A 10-yr cycle was worked out for application of sewage, tillage, and rotation of crops. Numerous tables of results of original investigations are included in this report.

Chase (14) has emphasized the need for observing proper disposal methods in relation to spray irrigation of pasture and wooded areas, with domestic wastes. He gives explicit directions in regard to required pretreatment, allowable volumes according to conditions, spray nozzle arrangement, prevention of harm to foliage, and other details of application. Deep silty soil is preferable. Clay subsoil may lead to bad effects from absorption of sodium through ion-exchange.

Stone (115), and Sloan (107) have discussed Merz's (76) report on sewage effluents for golf courses. Stone emphasizes the need of long-time storage of the chlorinated effluent, improving disinfection through prolonged chloramine contact time; the fertilizing value due to potash, phosphate, and nitrogen content; and proper engineering planning to prevent chloride and boron poisoning of the soil. Sloan reports on the use of the effluent from the 0.5-mgd Virginia Keys activated sludge plant at Miami, Florida. The effluent, before being applied to a golf course, is treated by rapid sand filtration, then diluted with city water to reduce chloride content from 1,300 to below 960 mg/l.

A report by Loewenstein (69) enumerates the process effluents of a coal, oil, and gas corporation of South Africa, totaling 10 to 11 mgd. To this is added a domestic sewage flow of 0.5 mgd. The treatment of the combined effluents, preparing them for reuse, is explained. Numerous flow diagrams and tabulations of chemical characteristics are presented. Erlich (24) has reported that a master plan for collection, treatment, and sea disposal of the sewage of Haifa, Israel, had been prepared for a future population of 450,000. But consideration of the water needs of the region, both for agriculture and future industry, brought a change of plans. An American engi-

neering firm was employed for changing the plans so as to provide for future agricultural and industrial reuse of the treated sewage. The main features of the changed plans are included in the report.

The need for the reuse of the total of Texas' municipal wastewater is the emphasis of a report by Connell and Berg (17). An evaluation is given of the availability and reusability of Texas' present total of treated sewage, more than 500 mgd. It is estimated that the total will exceed 1,000 mgd by 1975. And it is reasoned that this should be used approximately as follows: 50 per cent directly for industrial water supply; 25 per cent directly for irrigation; and the remainder indirectly for these purposes, plus domestic and recreation needs, soon after dilution in raw water sources.

Berger (8) has presented a comprehensive analysis of public health considerations as related to possible use of treated sewage for municipal water supply. He reviews the knowledge, and emphasizes the lack of knowledge, of the effectiveness of sewage and water treatment processes in removing pathogenic organisms and harmful chemicals. His final conclusion is: "A combination of current sewage and water treatment processes should not be considered adequate to convert sewage to safe drinking water. The recovery of the 99.9 per cent of pure water in sewage requires further study of the microbial and chemical challenges involved. Expanded research on advanced water cleansing processes is necessary."

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INSTRUCTORSHIP IN OPERATIONS RESEARCH

The School of Civil Engineering at Cornell University has available an instructorship in the Department of Sanitary Engineering, starting July 1, 1961. This new position represents a unique opportunity to participate, on a full- or part-time basis, in a sponsored departmental study involving the application of systems analysis (operations research) methods to sanitary engineering. Preference will be given to doctoral candidates with a master's degree in sanitary engineering and a thorough preparation in mathematics. Instructors may earn residence credit toward advanced degrees. The stipend will be in the $5,500 to $6,500 range, depending on the work load, for eleven months.

Interested individuals should write to Charles D. Gates, Professor of Sanitary Engineering, Hollister Hall, Cornell University, Ithaca, New York.

WHERE DOES RESEARCH STAND IN WATER POLLUTION CONTROL?

H. G. Hanson and Bernard B. Berger

Today many organizations with specific interests as well as Congress are giving most serious consideration to the state of the nation's water resources. There is a prominent position open in the front line of action to protect and preserve water resources for their highest purposes. How best to take advantage of this opportunity is a collective responsibility which can no longer be avoided.

It may be quite appropriate to the times that such topics as this are phrased as questions. This appears to be a period of history characterized more by questions than by answers, or more by what is not known than what is known. While there may not be a real depression of progress in acquiring new knowledge in this field, it certainly does not seem that there is at present a state of high prosperity of ideas.

In keeping with the spirit a few questions will be asked in this paper. They are reasonably straightforward and they can be answered at least in part.

Who is doing research? What research is being done? What are the resources for doing research? Taken in perspective, these questions should provide the basis to probe more deeply into the potential responsibility of this Federation.

Who Is Doing Research?

According to the recently published inventory of water supply and pollution control research projects in the United States (1), 95 agencies were engaged in such research in 1958, the latest year for which relatively complete information was available (Table I). Two-thirds were universities; 15 were industrial concerns and associated research laboratories; 11 state and interstate agencies and 3 municipalities were conducting research. A single federal agency, the Public Health Service, completed this particular inventory. The introduction to this survey recognized that this first report did not include all work in progress, but it is the best source of data available.

The greatest number of research projects, 205 out of a national total of 280, were carried on by the universities (Table II). The Robert A. Taft Sanitary Engineering Center consti-

TABLE I.—Number of Agencies Engaged in Water Supply and Pollution Control Research

(From Inventory of 1958 Research Projects)

Type of Agency	Number	Per Cent
University	65	68
State and interstate	11	12
Federal	1	1
Industrial	15	16
Local	3	3
Total	95	100

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TABLE II.—Number of Water Supply and Pollution Control Research Projects by Type of Agency

(From Inventory of 1958 Research Projects)

Type of Agency	Number	Per Cent
Universities	205	73.2
State and interstate agencies	25	8.9
Federal agencies	23	8.2
Industrial organizations	17	6.1
Local agencies	10	3.6
Total	280	100.0

tuted the largest single focus of research with 23 active projects.

A large proportion, approximately one-third, of the university research was conducted by departments other than that of Civil Engineering and Sanitary Engineering (Table III). The participation of these other departments was even more marked in research supported by the Public Health Service research grant program. This points to an expandable and versatile research resource, complementary to conventional sanitary engineering resources.

What Research Is Being Done?

The most comprehensive review of current research in water pollution is the literature review published annually (2). It covers both the national and international effort.

Most research projects in water pollution control will fall into one of six significant categories: (*a*) origin and behavior of wastes, (*b*) treatment of wastes, (*c*) disposal of effluents, (*d*) stream monitoring and surveys, (*e*) treatment of water, and (*f*) conservation (Table IV). It may not be surprising that the greatest number of projects in the 1958 inventory were in waste treatment. The general impression from graduate students is that this is the area of greatest interest and challenge to them.

However, many of the titles of the research projects listed in the inventory suggest a concern for improved techniques of waste analysis—in essence a searching for better methods of identifying and measuring wastes.

TABLE III.—Number of Research Projects Conducted by University Departments (1958)

Item	Total	Per Cent	Total (PHS Support)	Per Cent (PHS Support)
Depts. of Civil Engr. and/or Sanitary Engr.	135	68	36	43
Other Univ. Depts.	64	32	48	57

TABLE IV.—Nature of Water Supply and Water Pollution Research Projects

(Inventory of 1958 Research Projects)

Nature of Research	No. of Projects
Origin and behavior of wastes	33
Sewage	(13)
Industrial waste	(20)
Treatment of waste	113
Sewage	(69)
Industrial waste	(44)
Disposal of effluents	5
Stream monitoring and surveys	63
Treatment of water	56
Process study	(53)
Storage	(3)
Conservation	10
Total	280

Here is an expression of a growing need for more precise understanding of contaminants and of the ability to remove or destroy them.

It may be assumed that much research of value, particularly in the basic sciences, is being conducted by agencies completely outside the field of water quality control—agencies that may never have heard of workers and needs in this field. Effective contact with such research represents a most challenging problem of communication in science, but not insuperable. For example, a presentation of the problem of analysis and removal of soluble ma-

terials in water before the recent Gordon Research Conference on Separation and Purification elicited a most encouraging response from the scientists present. A number of them, previously completely unaware of this problem, have indicated their willingness to undertake fundamental work significant to these interests. There is need for more of this kind of communication.

What Is the Resource for Doing Research?

The universities—more specifically, their departments of civil engineering and/or sanitary engineering—are the major foci of personnel engaged in water supply and pollution control research. These institutions and the Robert A. Taft Sanitary Engineering Center constitute the hard core of such research in the United States. An examination of these staffs should, therefore, indicate the extent of the effort and ability to cope with new and difficult problems of water quality protection.

A recent listing of university staffs (3) showed that only 218 persons associated with departments of civil engineering and sanitary engineering devoted all or part of their time to water supply and pollution control research (Table V). Of these, 160 were engineers, 24 were chemists, 27 were microbiologists, 3 were aquatic biologists, and 4 were physicists. The man-year equivalent of these 218 full and part-time workers is about 100 (not including students). The professional staff of the Sanitary Engineering Center in this same area numbers 45. Of these, 12 are engineers, 16 are chemists, 7 are microbiologists, and 10 are aquatic biologists. The major resource of research personnel, therefore, numbers 263 persons and something like 150 man-years in all disciplines. To this should be added persons associated with university departments other than that of civil and sanitary engineering, with state and interstate agencies, with industry, and with local agencies. Unfortunately, the numbers of such persons have not been reported. However, assuming a figure of 150 for these groups, it may be estimated that 400 to 450 professionally trained persons, full and part-time, are engaged in water supply and pollution control research in the United States.

TABLE V.—Personnel Engaged in Water Supply and Pollution Control Research in University Departments of Civil Engineering and Sanitary Engineering and at the Sanitary Engineering Center

(From Sanitary Engineering Education Directory)

Professional Discipline	Number at Universities	Number at S.E.C.
Engineers	160	12
Chemists	24	16
Microbiologists	27	7
Aquatic biologists	3	10
Physicists	4	0
Total	218	45

In 1958, $3.5 million from all sources was estimated to be spent in support of water supply and pollution control research (Table VI). Approximately one-half was contributed by the federal government through direct research operations and by research grants. State and interstate agencies made $928,000 available for research, a large part of this sum representing federal grants-in-aid to these agencies. It was reported that industry spent

TABLE VI.—Amount of Water Supply and Pollution Control Research Support by Type of Agency

(From Inventory of 1958 Research Projects)

Type of Agency	Amount	Per Cent
Universities	$ 143,000	4.1
State and interstate	928,000	26.5
Federal	1,878,000	53.6
Industrial	404,000	13.3
Local	87,000	2.5
Total	$3,500,000	100.0

$404,000 for research—there must be much more than that—and that lesser sums were contributed by universities and municipalities.

The nation's developed resource for research in water supply and pollution control seems extremely small, if, with a population of 170 million, only 450 persons are engaged in research to provide the knowledge necessary for protecting the quality of the water resource. Looking at it another way, of the gross national product of $500 billion, only $3.5 million, or approximately $7 per $1 million of product, was spent for water pollution control research. Compare this with the $16,000 per million dollars of gross national product spent by industry on research to develop new products, the production and use of which contribute heavily to the problem. The lack in the waste and water treatment plants of laboratories well-equipped and staffed for investigative work, has been commented on by foreign colleagues, who note also a lack of investigative work by local jurisdictions as compared to their earlier substantial contributions. While investigative activity by local plants appears to be on the decline in this country, just the reverse trend appears to be taking place in England and other countries in Europe. The latest information available indicates approximately 150 laboratories in waste treatment plants there are engaged in investigative work.

Even more startling is the report that in the entire nation only three physical chemists are known to be engaged in research on water quality protection. This does not include physical chemists so employed by industry. The very low numbers of chemists, microbiologists, aquatic biologists, and other scientists conducting research in this field should be a matter of concern to all.

The paucity of research personnel is not the only somber note provided by this analysis. One senses a fragmentation of program, a lack of coordination among projects, over-attention to refinements on one hand and inattention to major problems on the other.

Given the small research resource described, there might be hope for its best use through efficient cooperation and planning among agencies. Unfortunately, joint planning at least is the exception, hardly the rule. A good example of its lack is seen in relation to the development of the waste stabilization pond method of treating sewage and industrial wastes. Probably no recent development in the field of sanitary engineering has excited the interest of municipal officials and the lay public as readily as has this cheap, effective method of sewage treatment. Industry also has shown a mounting interest in employing stabilization ponds for treatment of industrial wastes. In spite of this nation-wide interest which clearly responds to an important need, research on the fundamental principles of pond performance and on the development of design criteria remains fragmentary, uncoordinated, and spotty. There is speculation as to whether it is possible for diverse agencies to cooperate effectively in sanitary engineering research enterprises.

The foregoing description of the size, composition, and distribution of research resources is intended to convey an idea of what there now is to face the problems of the future. Attention should now be directed to the adequacy of knowledge with respect to water pollution control.

While the research resource remains small and almost static, the problems at hand are increasing in number and complexity. As the nation grows, these problems will become even more difficult. Already they extend to every facet of the behavior and fate of a waste in receiving waters and its effects on important water uses.

The shape of this multiphased water quality problem now discernible may

be outlined. However, it is not necessary to stress the gloomy or discouraging aspects of the situation. Rather, this should be considered an essential preliminary to a course of positive action.

The problems are presented as questions, starting with the origin of the waste and terminating at the point of water use:

1. Can there be an accounting for all of the wastes reaching streams?
2. Can the pollutional character of new wastes be predicted?
3. Can wastes be treated adequately?
4. Is effective use made of the receiving water?
5. Can receiving waters be monitored intelligently and effectively?
6. Can polluted water be effectively treated for reuse?

Each question will be discussed briefly.

Accounting for All of the Wastes Reaching Streams

Water pollution normally is associated with sewage and industrial wastes. Only recently has there been a consideration of the growing pollutional effect of land drainage, particularly that from agricultural lands. Even more recently has there been an awareness of pollution resulting from chemical poisons deliberately applied to the water course to kill weeds, insect larvae, fish, and other forms of aquatic life. Thus, there are at least four major avenues through which man-made pollution may reach streams: sewage, industrial wastes, land drainage, and direct chemical applications. A fifth whose actual significance has yet to be evaluated is the underwater emission of motor exhausts.

These, then, are the major ledger entries. Difficulty is encountered when proceeding with the accounting. First, it is possible to account qualitatively and quantitatively for only one-third of the soluble organics in the effluent from secondary sewage treatment. The situation with respect to industrial wastes is much worse. As for chemicals from land drainage and sources other than the easily located sewer, there can only be a guess.

Predicting the Pollutional Character of New Wastes

Can there be a reasonable prediction of the effect of the waste on the dissolved oxygen of the stream, its toxic effect on fish and other aquatic life, its tainting effect on fish flesh, its possible damage to water treatment processes, its effect on water palatability, and its short- or long-term effect on persons who drink that water?

Experience indicates that a well-equipped and well-staffed laboratory can obtain the information needed to predict with reasonable confidence, the probable impact of a new waste on certain important downstream water uses. However, the procedures are somewhat expensive and time-consuming and the laboratories available are few. Hence, the effort is not widely made. The toxicological phase of characterizing a waste is perhaps its most perplexing aspect. The specialized services and cost necessary for determining the effect of repeated exposure to low concentrations of the waste for long periods would inevitably place this job out of reach of most public agencies. Equally discouraging, perhaps, is the probability that the toxicological study may take two years or longer. There is urgent need for a more economical and more sensitive procedure, a presumptive test, for prompt determination of the potential of a compound for harming man. It is hoped that colleagues in the fields of physiology and toxicology accept this challenge. The recent seminar on "Physiological Aspects of Water Quality" sought to stimulate their interest.

Adequate Treatment of Wastes

Many yardsticks of strength and character of wastes are in use: BOD

is unquestionably the most common. With the best treatment processes available, a BOD reduction of approximately 95 per cent may be obtained. A reduction in BOD does not mean that the objectionable mineral salts, nitrates, and phosphates, have been removed. Just the opposite effect is produced in sewage stabilization by secondary treatment—nitrates are increased. Likewise, many of the soluble organic constituents of wastes are not removed by conventional secondary waste treatment processes. Many persistent organics discharged in sewage and in chemical industry wastes do not have a BOD. They are essentially non-oxidizable or they exert their oxygen demand so slowly as to be considered non-oxidizable. Obviously, even a sharp reduction in BOD gives no assurance that such compounds have been removed or destroyed. How, therefore, can there be control of such persistent substances found to be undesirable?

Effective Use of the Receiving Water

More and more it appears that there can be less and less dependence on the stream to treat sewered wastes. Its capacity will have to be reserved for unsewered wastes, for a factor of safety, and for the residual demands of increased volumes of sewered wastes after they have been given the best possible treatment. Presumably, available knowledge and experience on lateral mixing and dispersion of wastes in streams should permit effective use of the stream's capacity for dilution. At present, streaks of waste may often be traced many miles along a watercourse. Obviously, the effective dilution capacity is not being used. This often poses stream sampling problems because of variation in waste concentration in a cross-section of a stream. It also raises pertinent questions regarding the adequacy of outfall design. There may be some speculation as to what use is being made of the science of hydrodynamics.

Many have personal knowledge of the relatively poor state of the art of waste disposal into tidal waters. The field of sanitary engineering offers no question more profound than the following: "What is the fate of a particle of waste discharged into a mass of tidal water?" Every one of the 24 coastal and Gulf states will inevitably seek an answer to this question, a research task for colleagues in oceanography.

Intelligent and Effective Monitoring of Receiving Waters

The monitoring problem has three important phases: (*a*) to define what constitutes meaningful data for a given water resource; (*b*) to apply appropriate sampling and analytical procedures; and (*c*) to fit these data into a most practical scheme of water uses, waste discharges, and stream flow. This is a simple definition—but it covers the entire scientific base for water quality management. It offers tremendous opportunity for research on instrumentation, and on information recording and use.

Effective Treatment of Polluted Water for Reuse

The main function of the modern water treatment plant is to remove particles suspended in the water, and to destroy microorganisms that manage to survive flocculation and filtration procedures. Except for removal of hardness, little attempt is made to remove soluble chemicals in drinking water. Where taste and odor are highly objectionable, carbon is usually applied. But carbon is selective in its action, and sometimes it is ineffective. There actually is little known about the principle of adsorption as it applies to the use of carbon. Moreover, there is no assurance that harmful substances in solution will signify their presence by producing taste and odor. Here, as in waste treatment, interesting research opportunities exist. For it is certain

that more and more water must be reused again and again.

The Problem of Separation and Purification

Emphasis on the relative crudeness of techniques for separating and identifying contaminants, particularly complex organic compounds, has been deliberate. This difficulty underlies many important problems. It is encountered in characterizing composition of a waste, in treating biologically resistant organics, in examining polluted waters, and in purifying water for municipal and other uses. The dissipation of major uncertainties in dealing with these contaminants hinges on the development of highly effective means for their separation and analysis.

The Sanitary Engineering Center has recently initiated research in the improvement of separation techniques. Principles of separation essentially new to sanitary engineering, though not in the field of science, will be studied for the application to problems in sampling, concentration, and purification. In this program it is proposed to explore, largely through contract research, such techniques as foam fractionation, emulsion fractionation, freezing, polymeric ion exchange, gas hydration, modified adsorption techniques, membrane processes, and other separation procedures based on fundamental principles of physical chemistry.

These separation phenomena may be new to many. More will be heard about them in the future. Within present working lifetimes laboratories will be using such procedures to refine analytical procedures and define difficult pollution problems. Further in the future they may be expected to serve as the basis for development of new purification methods.

Some may feel that the time is not yet for this kind of approach—that the need is not urgent enough—that the problem today is not sufficiently critical. This may be so. But nature is not always quick to reveal her secrets. Experience indicates that a lag of 20 years between discovery and practical application is not uncommon. By that time new practical applications will be needed.

Recommendations

Many questions have been posed. It is only fair that possible courses of action be suggested. There is of course no panacea, and none is offered. Specifically, it is proposed that those in the profession formally pool their intelligence in a coordinated effort to develop a national program of research.

There is precedent for this approach. In the field of oceanography the profession has developed a comprehensive program designed to bring the science of oceanography to a level commensurate with the problem and needs. This has been a coordinated national effort. It has received wide attention by public and private groups, the Congress, and the President's Science Advisory Committee. Currently this same Committee is reviewing the national effort in the field of atmospheric sciences.

There is more than one avenue of approach to parallel action by the profession. The Federation itself might, for example, undertake to convene appropriate groups to plan and inaugurate a national program. Through the recent National Water Pollution Conference the nation's attention was directed to the need and to a course of action.

To sum up—population growths, industrial development, and scientific discovery itself, forecast an unprecedented and almost unpredictable set of demands on water resources. An avalanche of wastes, old and new, will challenge waste treatment technology and water quality control as never before. Present waste treatment and water quality control resources, and their rate of development, do not appear

adequate to future needs. Much is heard about "breakthroughs," mostly in the sense of scientific discovery. It is suggested that what is needed is a "breakthrough" in the magnitude of the national water pollution control research effort. The opening theme presented "questions." A question is offered to close the discussion. Will this Federation assume real leadership toward achieving such a "breakthrough?"

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NEW JERSEY MEETING

Prominent representatives to the 46th Annual Meeting of the New Jersey Water Pollution Control Association are shown in front of the Federation public relations booth. Those shown are Michael S. Kachorsky, President of the New Jersey Association; Maurice Brunstein, Superintendent of the Atlantic City Water Department; Robert S. Shaw, Chief Engineer of the New Jersey State Department of Health; and Sylvan C. Martin, Regional Engineer for the Public Health Service, New York City (Photo, courtesy *Philadelphia Inquirer*).

The New Jersey meeting is one of several at which the Federation public relations display will be shown this year.

REPAIRS TO CHELSEA SEWER

Paul P. Henderson

It would appear at first impression to be unreasonable to assume that a report on the repair of 200 ft of a trunk sewer could be of interest or value. However, considering the project reported herein with respect to some of the unusual problems encountered and how they were met, a certain amount of benefit might be derived.

Although no one thing can definitely be pointed out as the major cause for a failure such as the one under discussion, several factors common to other older trunk sewers built in coastal or tidal regions, or in the area of large waterways, could contribute singly or collectively. The following possibilities might be considered:

1. Movement of the subsurface water due to hydrostatic pressure of tidal action, eventually changing the ground structure and the stability of the sewer foundation (this sewer was 10 to 15 ft below mean low water).
2. Disturbance of the subsurface ground structure by construction of deep foundations, footings, or piers for new elevated highways, bridges, or sizeable commercial buildings nearby (in this instance, piers for the Mystic River Bridge).
3. Disturbance of the foundation base as the fines are carried off in the underdrain (borings showed fine wet sand in the vicinity of the Chelsea sewer break).
4. The pattern of laying brick in old trunk sewers around the turn of the century (this section had a vertical joint for the full 16-in. thickness of the invert, a situation conducive to fracture).
5. Corrosion and erosion of the steel plates over the arch, with resultant leaking of ground water through a cracked or weak masonry joint (this section is entirely below ground water level).

Whatever the cause, the effect is known. Fines carried off through the rupture in the sewer conduit create larger and larger voids, which in turn increase the size of the original break or cause new ones. Eventually a serious condition develops, necessitating repairs of major proportion. Such repairs constitute the scope of this paper.

Historical Background

To understand fully the events leading up to the failure of the Chelsea, Mass., trunk sewer, a brief description and history are given. The Metropolitan sewer involved was completed in the summer of 1893. Elliptical in shape, it was of brick and mortar construction, built partly as cut and cover with sheeted trench and partly as tunnel.

The break occurred in the tunnel section. This section was formed from the invert to 18 in. above the spring line by placing 16 in. of brick masonry on 2-in. wooden lagging, and from that point by lining the 3-ft by 1-ft

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The paper was presented at the 33rd Annual Meeting of the Water Pollution Control Federation in Philadelphia, Pa., October 2-6, 1960.

steel plates forming the tunnel arch with a minimum of 12 in. of brick masonry. The trunk sewer at this location had inside finished dimensions of 8 ft 10 in. by 9 ft 4½ in., with the invert approximately 45 ft below original ground surface.

Trouble first developed in the spring of 1948 when a City of Chelsea Water Department employee jumped down into a water service excavation 4 ft deep and disappeared from sight—his body, pressed against the outside of the sewer, was not found and recovered until 71 days had elapsed. Under ensuing contracts the sewer was inspected and found to have two cross-sectional cracks and a crack along the arch of the sewer for a distance of approximately 100 ft. On the advice of a soil consultant it was decided to stabilize the soils in this area by pressure grouting from 1 ft below the invert to 10 or 15 ft above the trunk sewer. This operation, although accompanied by a few local sewer stoppages and disconcerting eruptions in adjacent cellars, was completed on October 6, 1949.

No further trouble was experienced with the Second Street sewer until May 1954, when two holes—apparently 1 ft in diameter and 1 ft in depth—appeared in the gutter line paralleling the Metropolitan District Commission's 42-in. cast-iron water main. Investigation showed the holes to extend under the sidewalk over the water line; approximately 35 ft of the line was uncovered, but no leaking joints were found so the pipeline was backfilled and the sidewalk repaired.

Holes again appeared in the street surface of Second Street, Chelsea, on April 1, 1955. House sewer services were found to be broken and the 24-in. local sewer was partially filled with sand and clay. This condition seemed to account for the holes and settlement in the area. The sewers were repaired with the hope that this would end the series of voids. However, on May 7, 1955, a large hole appeared opposite this location. This was filled with gravel. Again on May 28 another hole opened in the center of Second Street. This also was filled.

The final opening appeared on June 6. In a matter of hours a pit 20 ft deep and 20 ft in diameter grew, with materials funneling through a hole about 4 ft in diameter at the bottom. Hay and miscellaneous fill were dumped into the void to stop the enlarging of the hole, which by this time threatened to undermine the foundations of the three-story tenement houses along the street. Emergency action was taken and a contractor who had a large supply of steel Z sheet piling was pressed into service. Driving of sheeting was begun immediately to prevent loss or collapse of the adjacent dwellings.

Preparation for Repair

The sheeting was originally intended to enclose an area 18 ft wide and about 75 ft long, but based on earlier inspection of the interior of the trunk sewer and the arch cracks noted at that time, the sheeted area was extended to almost 200 ft—practically the entire city block. An over-all view of the work site is shown in Figure 1.

A double row of 40-ft Z sheet piling was driven along both sides of the location; the inner row to about 5 ft below the invert of the trunk sewer and the outside line until the tops were near ground level. As excavation proceeded 14-in. H-beams were set as both walers and cross-braces. As an extra safeguard to ensure that the 14-in. H-beam walers would be better able to withstand not only the terrific pressures existing on the outside but also the stresses incurred or induced by the shock and vibration of pile driving, ½-in. steel plates were cut to fit the webs of the H-beams between their flanges. These plates were welded on the top and bottom of the walers at every intersection with cross-members.

The added strength, rigidity, and safety produced by these plates more than made up for the delay of welding them into place.

Local sewage was bypassed through a 15-in. steel pipe fastened to the sheeting, with temporary connections cut in for house services. Old truck tire tubes and stove pipes worked exceptionally well in this capacity. The discharge end of the steel pipe was connected directly to the trunk sewer

FIGURE 1.—Over-all view of work site on repair of Chelsea, Mass., trunk sewer.

downstream from the break. Temporary water service connections were made in the usual manner.

After the temporary local services had been taken care of and the area had been adequately protected for safety, the first serious consideration was given to the details of repairing the old Metropolitan sewer. Fortunately, a new relief sewer had been constructed in 1938 paralleling the trunk sewer although still several hundred yards away. With this as a means of eliminating the main sewage

FIGURE 2.—Sandbag dam installed upstream in brick trunk sewer to collect local sewage inflow for bypass pumping.

flow coming from the north, it was decided to place a bulkhead in the trunk sewer approximately two miles upstream, forcing the sewage to reverse flow through an existing cross-over and discharge through an overflow into the relief sewer. Another bulkhead was placed within the confines of the excavation just downstream from the break.

These bulkheads were made up of 10-in. and 12-in. steel I-beams used as uprights and cross-members, with approximately 5 ft between the front face and the back face. The front face of each bulkhead was made up of 3-in. by 12-in. tongue-and-groove planks; ½-in. thick rubber 10 in. wide was placed "shiplap" laterally along the front face. The 5-ft interval between the two faces was filled with

FIGURE 3.—Steel-plate sluice in downstream bulkhead to relieve storm water flooding.

FIGURE 4.—Installation of wellpoints to control ground water flow into excavation.

clay, and irregularities in the face structures were filled by sandbags.

Now that the main flow was eliminated, provisions were made to care for the local sewage of those sections of the cities of Everett and Chelsea that discharged into the trunk sewer between the upstream bulkhead and the location of the break. A 5-ft high sandbag dam was built inside the brick sewer upstream (Figure 2). Two 6-in. centrifugal pumps, driven by electric motors and designed to handle approximately 7 mgd, were installed on a platform just above the trunk sewer.

Unhappily, during later rain and snow storms, it was learned that the local sewers of the two cities were in many instances combined systems. After the work was flooded out twice, a third trash pump 8 in. in diameter and designed to handle 5 to 6 mgd was installed, giving total pumping capacity of 12 to 13 mgd for local sewage. This, unfortunately, still proved to be insufficient capacity to handle heavy downpours—but the condition was accepted, albeit with great reluctance.

It can be readily understood that during these overflows the downstream bulkhead provided an unwanted dam. To reduce this undesirable flooding and to cut down on the pumping time for return to work, a sluice made of ½-in. steel was installed in the downstream bulkhead. This sluice (Figure 3) was

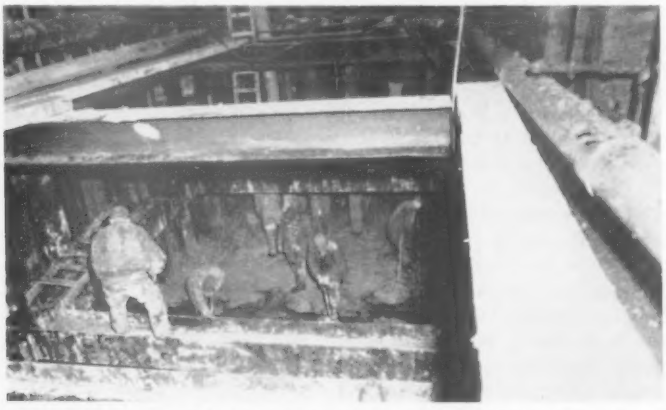

FIGURE 5.—General view at Station 19 + 75 during excavation. Note wellpoint headers at left and right, and 15-in. temporary local sewer at upper left.

FIGURE 6.—General view at Station 18 + 75 during excavation.

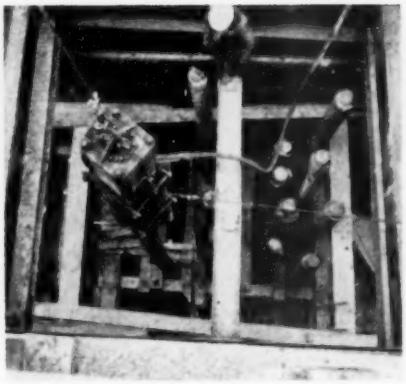

FIGURE 7.—Pile-driving operations at about Station 19 + 50.

approximately 2½ ft high and 3½ ft wide, with a plain but effective steel-plate flap on the downstream end. When it rained the flap was opened and the overflow passed through the sluice, no longer necessitating removal of all the pumping equipment from the platforms.

Ground water was controlled by the use of 80 wellpoints (Figure 4) distributed along the inside of the sheeting and connected to 8-in. header lines. Pump capacity was provided by an 1,800-gpm diesel pump with a 1,200-gpm gasoline pump for standby and auxiliary use. A "mop" was attached to the diesel pump to take care of local water within the excavation. General views of the excavation progress are shown in Figures 5 and 6.

Construction and Repair

In designing the replacement for the old brick sewer, it was decided that 96-in. reinforced concrete pipe would be used, connected by a cast-in-place transition at the downstream end. At the upstream end of the break a stop-log chamber was called for. In effect it was to be a multi-purpose structure. It would serve as a transition between the old elliptical sewer and the new round one, would provide the means for shutting off flow downstream for inspection of the old trunk sewer, and in the event a future break or failure occurred a bricked opening could be removed and an emergency pipeline connection made to the previously mentioned relief sewer.

Wooden piles were driven (Figure 7) for support of the stop-log chamber and pipeline. At times, due to the pile driving, the bottom of the excavation became "active." This was increasingly true as the job progressed and the efficiency of the wellpoint system decreased. As the fines and water bubbled up in a mild artesian effect around the pile being driven and those in close proximity, it was found possible to check the "action" by excavating around the piles and packing with crushed stone. Cutoff grade for the piles was 2.5 ft below invert and 1 ft above subgrade.

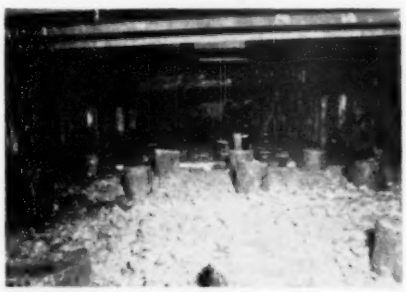

FIGURE 8.—Pile arrangement and 6-in. crushed stone blanket.

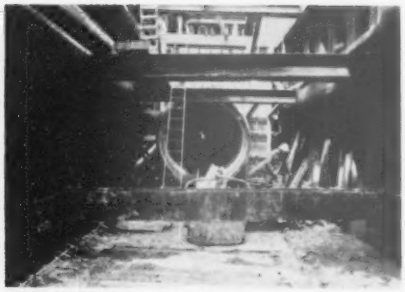

FIGURE 9.—Reinforced concrete mat 2 ft thick stabilized trench bottom.

A 6-in. blanket of crushed stone was then spread over the entire bottom (Figure 8) and a 2-ft reinforced concrete mat (Figure 9) was placed across the trench between the side walls of steel sheeting.

To prevent damage to the conduit in the event voids might occur beneath the mat due to some future fracture in the old section of the sewer, ¼-in. plywood was set as a continuous vertical slipjoint at the two outside edges of the pile pattern.

Next, the pipe was set on precast concrete blocks and a cradle of concrete was placed underneath and 2 ft up the sides of the pipe (Figure 10).

The downstream transition section was originally intended also to be constructed on piles; but the "boiling" of the bottom became so hazardous in this area during any attempt to drive piles, that another method of stabilizing the ground had to be employed. An additional 2½ ft was dug out and the area was filled with crushed stone. Extra reinforcing steel was added to the mat and the transition concrete was placed.

Finally the breach had been closed. The two main bulkheads and the sandbag dam were removed and once again sewage flowed in a normal manner through the Metropolitan trunk sewer. At the location of the bulkhead 2 miles upstream, a novel method was conceived to replace the section of arch removed for installation. A sheet of 10-gage steel was used as the inside form. It was held in place and shaped to the arch by means of turnbuckled cables attached to clips welded onto the steel sheeting originally driven for placement of the bulkhead. Reinforcing was cut to fit and to bridge the opening; concrete was placed, making an effective seal and cap.

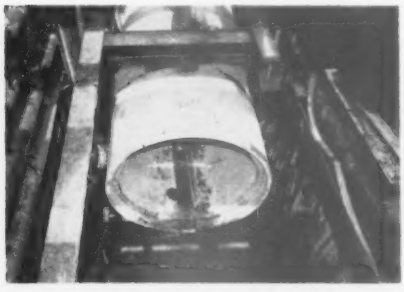

FIGURE 10.—Concrete cradle beneath and 2 ft up sides provided further pipe support.

FIGURE 11.—Proper compaction was obtained by using pneumatic tamps on each layer of gravel or tunnel muck, then wetting the fill with a fire hose.

Backfill was placed under ideal conditions, both from an engineer's and a contractor's viewpoint. Payment for repair of the trunkline was on a cost-plus basis; naturally, no argument arose when compacted layers of fill 8 to 12 in. in depth were required. Gravel refill was placed to approximately 3 ft over the pipe. Next, 10 to 12 ft of rock tunnel spoil was placed;

FIGURE 12.—Local underground utilities were replaced by usual construction methods.

from that elevation to the subgrade of the finished street surface, gravel was used.

Pneumatic tamps were employed (Figure 11) to get proper compaction, with each layer of gravel or tunnel muck then thoroughly wet down by fire hose as added insurance. So effective was the compaction that even though the finished surface of the street was laid without the usual 6 months of traffic use over temporary pavement, there has not been even so much as ½ in. of settlement in these ensuing four years.

New water, local sewer, gas, and telephone lines were laid and new house service connections were made by

FIGURE 13.—Bituminous concrete surface 1½ in. thick (left) was placed over 2 in. of bituminous concrete binder (right) on 4-in. base of bitumen-penetrated crushed stone.

the usual construction methods (Figure 12). Ends and outside rows of steel sheeting were pulled, but the inner rows were left in place as a safety measure. Granite curbing was set and monolithic concrete sidewalks were placed.

The steet was repaved in the following manner. First, a 4-in. base of crushed stone penetrated with bitumen was laid. This was followed by 2 in. of bituminous concrete binder, and finally a 1½-in. surface of bituminous concrete top was placed (Figure 13).

Thus finally ended a most difficult, costly, and tedious project. The day-to-day problems that had to be met and the solving of the same by innovation and practical, yet now and then crude designs, were an education one must be considered fortunate to have experienced. It is hoped that at least a few ideas, which will be of some value in the future, have been passed along.

YOUR FRIENDS WILL BE LOOKING FOR YOU IN MILWAUKEE IN OCTOBER. SEE PAGE 505

EXPERIMENTAL TREATMENT OF ORGANIC CYANIDES BY CONVENTIONAL PROCESSES

F. J. Ludzack, R. B. Schaffer, and R. N. Bloomhuff

An earlier presentation (1) described studies on the behavior of certain nitriles in surface water. The current discussion presents an extension of this work to consider treatability of the same nitriles by activated sludge and anaerobic digestion.

The previous studies reported results on slug doses of nitriles in river water. The activated sludge studies, described subsequently, were based on a semicontinuous feed of nitrile and supplementary sewage to bench-scale units. Anaerobic digesters were fed with the nitrile and a reference feed in batch increments.

Activated Sludge Experimental Details

The bench-scale activated sludge unit adopted for this study is described in an earlier paper (2). A schematic diagram is presented in Figure 1.

A 17.5-l activated sludge stock tank somewhat similar to the test units was maintained on dog food meal and sewage to start or replace sludge in the 5.5-l test units.

Test units received a feed consisting of weak settled sewage (BOD normally 50 to 75 mg/l) containing the test nitrile. About 70-per cent nitrile oxygen demand was intended for acclimated normal operation. Actual loading varied from 50- to 90-per cent nitrile oxygen demand depending on the stage of acclimation, the particular nitrile, its concentration, and sewage strength. Sewage was used to provide supplementary nutrients.

Feed introduction time varied from 12 to 23 hr of the day. Rates were adjusted to introduce approximately one-half of the total load from 9 AM to 4:30 PM, with the remainder continuing through the night. Solids or liquid inadvertently left in the influent reservoir on the following morning were added rapidly to the aerator. The semicontinuous feed rate approximates load variations in municipal or industrial treatment systems resulting from population activity, process variations, or cleanup periods. The units were not dosed on Saturday and Sunday.

Usual feed volume was 9 l/day, 18 l/day in some tests. Mean aerator detention time was about 13 and 6½ hr, respectively. More concentrated feeds were used in preference to short detention to permit better evaluation of toxicity and reduce sewage handling. The sewage was chilled at 5°C overnight to decrease biological changes during the feed sequence.

Loading was calculated on the basis of sewage BOD plus the calculated carbonaceous BOD of the test nitrile. The theoretical amount of oxygen required for nitrile oxidation (Table I) was obtained according to the relations ex-

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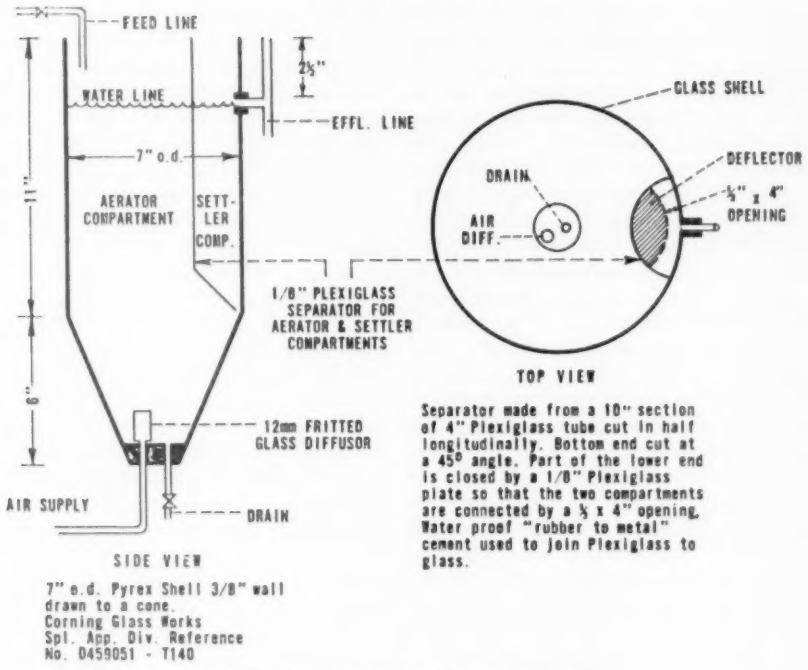
FEED LINE
2½"
WATER LINE
EFFL. LINE
7" o.d.
11"
AERATOR COMPARTMENT
SETT-LER COMP.
6"
1/8" PLEXIGLASS SEPARATOR FOR AERATOR & SETTLER COMPARTMENTS
12mm FRITTED GLASS DIFFUSOR
AIR SUPPLY
DRAIN
SIDE VIEW
7" o.d. Pyrex Shell 3/8" wall drawn to a cone. Corning Glass Works Spl. App. Div. Reference No. 0459051 - T140
GLASS SHELL
DEFLECTOR
DRAIN
AIR DIFF.
½" x 4" OPENING
TOP VIEW
Separator made from a 10" section of 4" Plexiglass tube cut in half longitudinally. Bottom end cut at a 45° angle. Part of the lower end is closed by a 1/8" Plexiglass plate so that the two compartments are connected by a ½ x 4" opening. Water proof "rubber to metal" cement used to join Plexiglass to glass.

FIGURE 1.—Model activated sludge unit.

pressed in the following for adiponitrile:

$$CNC_4H_8CN + 6\tfrac{1}{2}O_2 \rightarrow 6CO_2 + H_2O + 2NH_3 \quad (1)$$

Molecular weight of adiponitrile is 108, for which the oxygen equivalent is 208. Theoretical oxygen demand, therefore, is 208/108 or 1.93 mg of oxygen per mg of adiponitrile for carbonaceous oxidation. Complete oxidation of both nitrogen and carbon would result in formation of water and nitric acid in place of the ammonia, with a corresponding increase in oxygen requirements. The new equivalent would be 3.22 mg of oxygen per mg of nitrile. Daily load ratios were expressed as a dimensionless weight ratio representing influent oxygen demand in terms of

TABLE I.—Pertinent Physical and Chemical Data on the Test Nitriles

Test Nitrile	Formula	Density	Theoretical BOD (mg/mg)		mg N/mg Nitrile
			C	C+N	
Aceto-	$CH_3—CN$	0.78	1.56	3.21	0.342
Adipo-	$NC—(CH_2)_4—CN$	0.92	1.93	3.22	0.259
Benzo-	$C_6H_5—CN$	1.01	2.33	3.39	0.136
Acrylo-	$CH_2=CH—CN$	0.80	1.81	3.31	0.264
Lacto-	$CH_3\underset{OH}{\vert}—CN$	0.99	1.35	2.25	0.198
Oxydipropio-	$O(C_2H_4CN)_2$	1.02	1.55	2.68	0.233

unit volatile solids (2) (that is, 40/100 = 40 parts of influent BOD/100 parts circulating volatile solids). The reciprocal of this load ratio provides an estimate of sludge age. Load ratios for different periods frequently overlapped because of sewage strength variations. No attempt was made to control this variable. Using the carbonaceous BOD for nitriles resulted in a minimum load ratio; nitrification could increase the actual load ratio by 33 to 100 per cent (Table I).

Units were operated at room temperature (22 to 25°C) for sufficient time to observe continuous performance during acclimation, normal, and overload periods.

Influent and effluent analysis included general determinations such as COD, BOD, suspended solids, and pH (3). Influent nitrogen included ammonia and organic nitrogen in sewage plus the calculated nitrile nitrogen added (Table I). Effluent nitrogen was based on ammonia, organic, nitrite, and nitrate determinations. These data were used for material balance and nitrogen conversion estimates. Effluent cyanide (3) was determined regularly on lactonitrile sludges; other nitriles tested failed to yield enough cyanide to exceed the analytical interference level. Specific nitrile determinations were impractical except for acrylonitrile (1). Nitrogen balances did not indicate significant nitrile breakthrough in acclimated units. The method of Daues and Hamner (4) and Stepanek and Cerna (5) applied to acrylonitrile activated sludge verified a negligible breakthrough of nitrile at load ratios tested. Effluent analysis was based on 48-hr composites preserved with mercuric chloride, excepting BOD samples collected separately during the maximum load period.

Solids analysis included mixed liquor solids, volatile solids, sludge density index (3), and percentage nitrogen in the volatile solids (2). The nitrogen percentage was useful in estimating sludge quality and for correcting the nitrogen balance for removed excess solids. Test unit solids analysis was obtained once weekly; any excess beyond 6.0 g of volatile solids per unit was discarded (adjusted mixed liquor volatile solids 1,000 to 1,200 mg/l). Sludge production per gram of influent BOD thus was lower than if solids had been removed daily.

An activated sludge was considered satisfactory in operation when (*a*) oxidation and clarification resulted in good oxygen demand and suspended solids removal; (*b*) foaming, attached solids, lumpy agglomerates, floating solids, or poor odor and color were not excessive; (*c*) microbiological populations showed a good variety of apparently active organisms; (*d*) the nitrogen percentage of sludge volatile solids approached that of active protoplasm; and (*e*) effluent analysis demonstrated that a significant fraction of feed nitrogen was being converted to nitrates.

A high percentage of nitrification normally is not a requirement of activated sludge operation. Results with nitrile feeds were such that poor nitrification usually preceded performance failure such as Item *a* in the performance criteria. The nitrogen percentage in the sludge volatile solids usually maintained an equilibrium range for a given feed and load. A significant drop in this value was the most reliable indicator that performance would deteriorate within a few days unless corrective measures were taken. Nitrogen analysis results therefore were used as the primary performance criteria in the discussion of results.

Activated Sludge Results

Material Balance and Nitrogen Conversion

Data on material balances and nitrogen conversion for several test runs are shown in Figures 2 through 6. Each of the tested nitriles was given a

preliminary run followed by two or more tabulated runs.

Bar graphs were used to show the proportion of sewage and nitrile nitrogen in the influent for acclimation, normal operation, and overload periods. Effluent ammonia, organic and oxidized (nitrite plus nitrate) nitrogen, and the nitrogen in removed sludge are expressed on the same bar graph as a percentage of the feed nitrogen for each period. These results show the material balance and degree of conversion of influent nitrogen under test conditions. Observation time, nitrile concentration, total feed nitrogen, and load ratio limits are also given for each period.

The acclimation period described does not indicate the minimum time required to produce a good effluent. Usually a low concentration of nitrile was used at the start of acclimation. The nitrile concentration was doubled at weekly intervals until nitrile oxygen demand was a major fraction of the total feed oxygen demand. Lag in analysis and performance estimates usually meant that dosage could have been increased more rapidly without ill effect. Because continuous performance estimates were desired, the acclimation period was extended to make certain that initial good performance was not a transitory condition. In general, good performance was achieved in one-fourth to one-half the stated acclimation time.

Acrylonitrile Treatment

Data on acrylonitrile treatment are presented in Figure 2. Integral re-

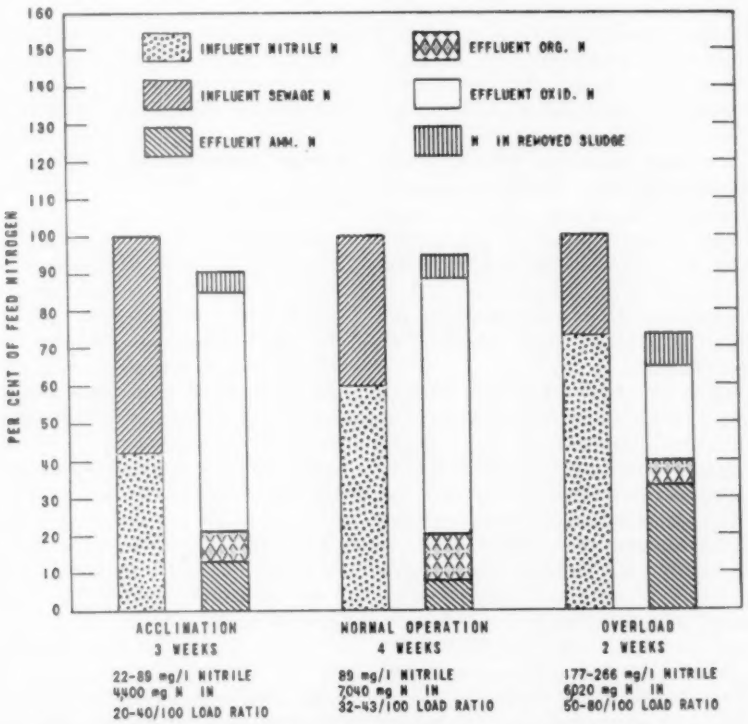

FIGURE 2.—Nitrogen balance for activated sludge on acrylonitrile plus sewage feed.

TABLE II.—General Performance Characteristics of Nitrile Activated Sludge

Acclimated Nitrile System	Range during Normal Operation				
	Carbon Influent BOD	% BOD Removed	g Sludge VS/g Infl. BOD	% N in Sludge VS	SDI
Aceto-	200–275	82–94	0.04–0.20	7.9– 9.2	2.0–2.5
Adipo-	275–350	93–98	0.10–0.28	9.1–10.6	1.7–2.3
Benzo-	300–400	93–98	0.12–0.40	9.5–12.0	0.9–2.0
Acrylo-	250–350	90–97	0.15–0.23	9.8–10.7	2.1–2.3
Lacto-	150–250	87–98	0.05–0.20	9.1–10.3	1.5–2.0
Oxydipropio-	225–325	89–96	0.07–0.15	8.3–10.9	2.7–3.2

sults of three weeks' acclimation show good conversion of nitrile nitrogen to oxidized nitrogen although initial results were poor. During four weeks of normal operation 60 per cent of the influent nitrogen as nitrile resulted in effluents containing 70-per cent oxidized nitrogen. The load ratio used is within customary limits for conventional domestic sewage activated sludge treatment. During overloading, sludge performance deteriorated at 177 mg/l of nitrile, but apparently could have adjusted for continuous performance at reduced efficiency. At 266 mg/l of acrylonitrile, treatment efficiency was materially reduced. The percentage of nitrogen in the sludge volatile solids decreased from a range of 9.8 to 10.7 (Table II) to less than 8.0 with the high nitrile feed. About one-third of the influent nitrogen appeared in the effluent in oxidized form under overload conditions.

During the overload period, effluent nitrogen analysis failed to account for a substantial fraction of the influent nitrogen. Poor material balances invariably occurred prior to breakdown, but this series is the only one presented in which dosage was high enough to show a large loss of nitrogen. Major contributing factors are likely to be associated with aeration loss of ammonia or denitrification resulting from oxygen deficiency. There was no evidence of acrylonitrile in the effluent.

The overload sludge was transferred to a recirculating gas unit in which carbon dioxide and ammonia were absorbed from the gas and replaced with oxygen. Ammonia in the gas was not detectable at a mixed liquor pH below 7.8 or ammonia concentration below 30 mg/l. The overloaded system failed to reach these limits, hence ammonia loss did not account for the poor material balance. Low effluent DO levels and high solids production during overloads easily could have resulted in oxygen-deficient local sludge agglomerates. Definite proof was not obtained, but results strongly suggest that denitrification was the major factor in nitrogen losses during overloads.

Acclimation

Acclimation data (Figure 3) for acrylonitrile, are divided into short periods to reveal the rapid changes in nitrogen conversion during early stages. The unit was started on what appeared to be a normal load range. A summation of the first four days' operation shows 40 per cent of the influent nitrogen as effluent ammonia. The poor material balance is partially due to a buildup of sludge nitrogen; most of it is likely to be the result of ammonia loss to the air. The next five days show an improved material balance, lower ammonia, and higher oxidized nitrogen in the effluent.

The third period shows about 90 per cent of the influent nitrogen as effluent oxidized material with about 20 per cent more nitrogen in the effluent than in the feed. The first two periods

(Figure 3) showed a rapid increase in solids and solids nitrogen. Solids buildup decreased during the third period. The percentage of nitrogen also decreased from a peak of 12 per cent to less than 11 per cent. Concurrent unloading of solids nitrogen accounts for most of the excess effluent nitrogen.

Behavior exhibited in Figure 3 illustrates the rapid changes in performance during the early phases of acclimation. The unit had not reached a steady performance level by the 13th day. However, Figure 3 shows that good effluents can be obtained in a much shorter time than that required to reach steady performance as shown in Figure 2. Moreover, acclimation was not delayed by starting the unit with a high initial load of acrylonitrile.

Nitrogen Balance for Lactonitrile

The nitrogen balance for lactonitrile and sewage is shown in Figure 4. Significant effluent cyanide appeared during the acclimation period and trace amounts during overloads. The system was unable to handle lactonitrile concentrations as high as those for acrylonitrile, but double the volume of influent at 165 mg/l nitrile dosage was treated for five successive days without upset. Recovery was rapid after the load decreased. The major effects of overloading were an increase in effluent ammonia and suspended solids with decreased oxidized nitrogen. Negative results were obtained for acclimation to lactonitrile when a full load was applied to a new sludge.

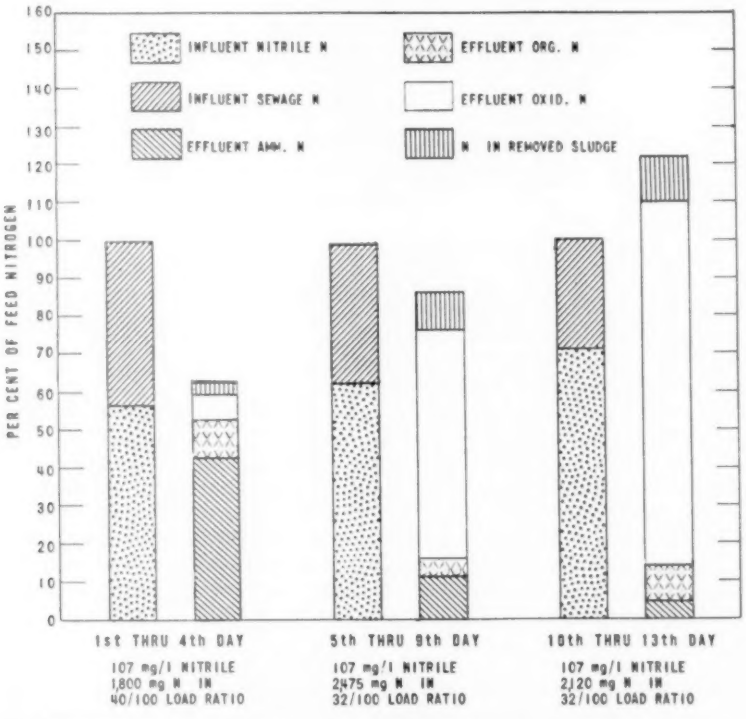

FIGURE 3.—Nitrogen balance for activated sludge on acrylonitrile plus sewage feed during acclimation.

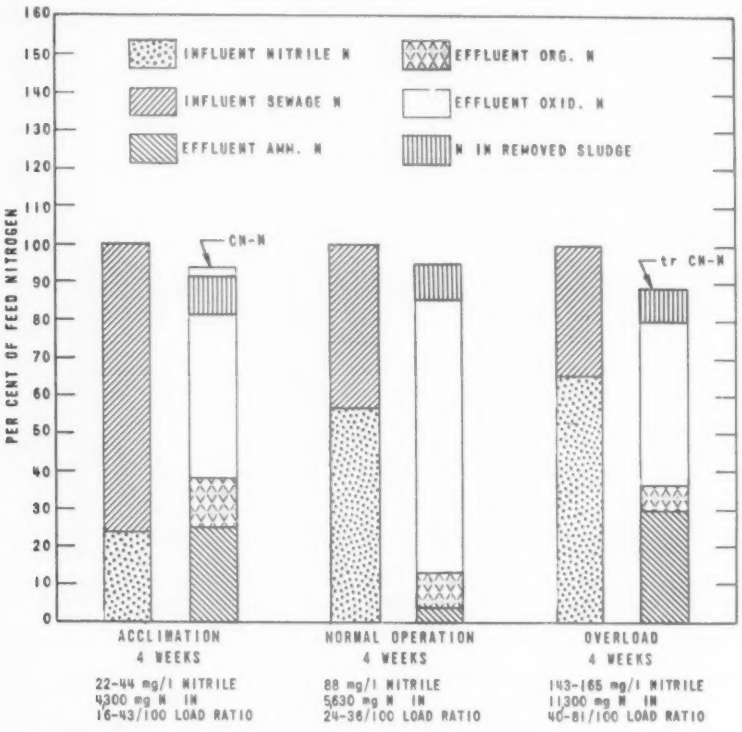

FIGURE 4.—Nitrogen balance for activated sludge on lactronitrile plus sewage feed.

Nitrogen Balance for Oxydipropionitrile

Figure 5 presents the nitrogen balances for oxydipropionitrile and sewage. This nitrile required an exceptionally long acclimation period in surface water (1). It failed to show unusual resistance to activated sludge treatment. Effluent organic nitrogen was high for a few days but decreased by the end of the first week of acclimation. High organic nitrogen would indicate oxydipropionitrile breakthrough in the absence of high suspended solids. It required about twice as long for acclimation with winter sewage as for summer sewage reported in Figure 5. Whether this time difference was the result of chance or of some microbial factor is unknown. Temperature of operation was similar for both. Good performance and material balance during overload indicate that substantially higher loading of oxydipropionitrile would be necessary for an upset.

Acetonitrile Behavior

Acetonitrile behavior as shown in Figure 6 is difficult to judge. Acclimation shows good adjustment; high nitrates appeared in the effluent in one week at reduced loading. Normal and overload periods show good conversion from nitrile to oxidized nitrogen but each succeeding period shows an increase in effluent ammonia. This system was characterized by low solids accumulation, low nitrogen in the volatile solids (Table II), and a highly dispersed floc. Although treatment appeared on the ragged edge of poor performance most of the time, it

achieved its purpose with a fair degree of consistency.

Other Data

Benzo- and adiponitrile data are not presented, as their behavior was not unusual. In general, both were relatively nontoxic and more amenable to treatment than other nitrile systems described.

Data other than those given with the nitrogen balance are summarized for the six nitrile activated sludges in Table II. Percentage BOD removals were good on all test systems, with acetonitrile units lowest. Volatile solids accumulation per gram of influent BOD indicated a wide range, with benzonitrile high and aceto-, lacto-, and oxydipropionitrile low. The data suggest that there are more factors involved in solids gain than BOD removal and loading. Volatile solids are expressed here because silt entering with the sewage in wet weather confused solids data. Volatiles normally amounting to 70 to 85 per cent were decreased to 50 to 60 per cent after heavy rains. Percentage nitrogen in volatile solids varied appreciably; lowest values appeared in aceto- and oxydipropionitrile sludges. It is interesting to note that the sludge with the highest percentage of nitrogen was fed with a nitrile containing the lowest percentage of nitrogen. The sludge density index was high in all test systems, with benzonitrile and oxydipropionitrile at the two extremes.

Experience with bench-scale units shows that a plant sludge starting with an SDI of about 1.0 will become in-

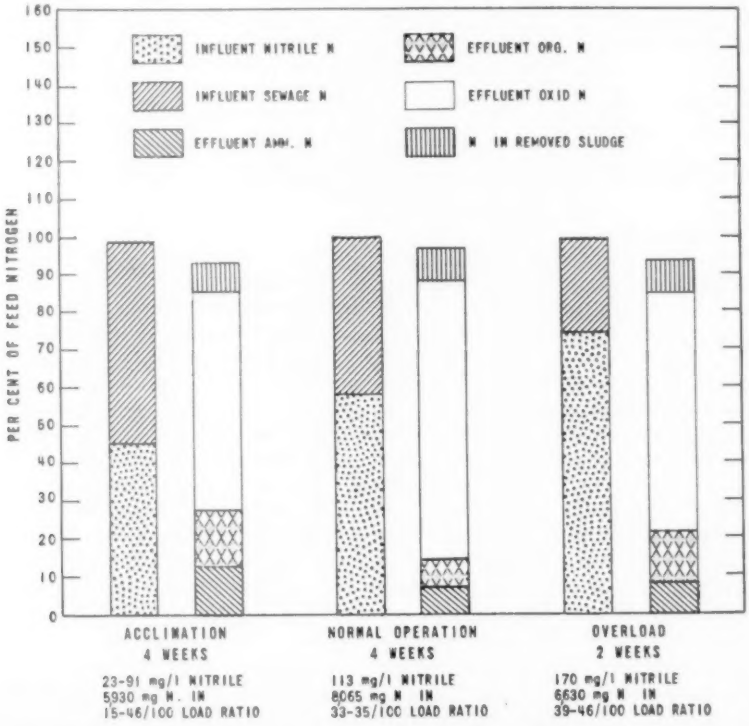

FIGURE 5.—Nitrogen balance for activated sludge on oxydipropionitrile plus sewage feed.

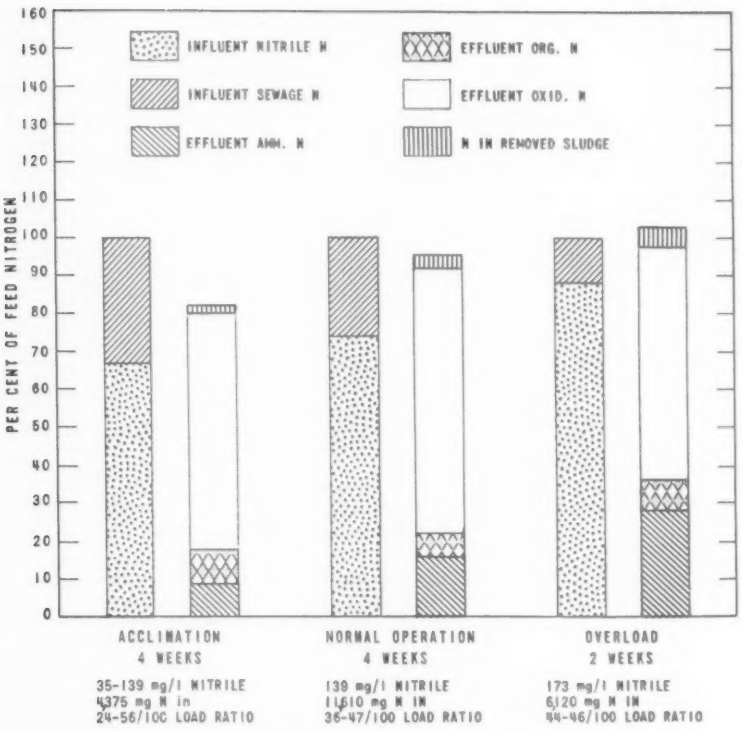

FIGURE 6.—Nitrogen balance for activated sludge on acetonitrile plus sewage feed.

creasingly dense after one or two days' operation in a small unit. Precise reasons for this are unknown, but they are likely to be associated with less efficient retention of the lighter solids in a small clarifier. Information for full-scale operation on solids density and air requirements is not likely to be precisely estimated on the basis of bench-scale tests.

Effluent suspended solids varied significantly, although many of the high values were due to the fact that the needle valves controlling air flow were somewhat unreliable for control purposes. Acetonitrile effluents normally ranged from 15 to 30 mg/l. Other units rarely exceeded 20 mg/l in suspended solids. It would be expected that high nitrate effluents would contribute to high floating and suspended solids. Relatively little difficulty of this nature was experienced in spite of nitrate concentrations occasionally exceeding 50 mg/l. A long period without overflow generally resulted in accumulation of floating settler solids. Settler agitation generally restored normal sedimentation and was a common Monday morning routine.

Ability to recover from an overload differed appreciably between nitrile sludges. Acrylonitrile sludge was slowest to reestablish good treatment; it frequently required as long for recovery as for acclimation of a new sludge. Overloads on acrylonitrile, therefore, should be avoided. This sludge also was more temperamental, and deteriorated treatment resulted from minor variations that did not affect other nitrile test units. Most of

the other nitrile sludges recovered from overloads within one to three days although acetonitrile showed minor performance differences at any test load.

Week-end starvation did not affect the treatment efficiency of the Monday load for any of the nitriles tested. Long-period starvation was tested on acrylonitrile activated sludge because this sludge was more temperamental and the chemical is more likely to be found in waste effluents. The acclimated sludge received no feed for 30 days, then was given a full load for 5 successive days, followed by another 30-day rest. Good performance was observed by the third day after the first rest period; a full load after the second rest period resulted in excessive solids in the settled effluent. For all practical purposes, the observed recovery from starvation was adequate.

Nitrile feeding in tap water to an acclimated sludge showed that acrylo-, lacto-, and oxydipropionitrile treatment deteriorated within one week. Other test nitrile cultures maintained efficiency somewhat longer. The precise functions of sewage in treatment efficiency were not determined. In all probability any mixture providing suitable supplementary nutrients would serve as well. It was obvious that nitrile sludges failed to maintain treatment efficiency for long without the addition of a mixed organic feed.

Cross-Acclimation

Data were obtained on cross-acclimation in surface water (1) by acclimating a system to one nitrile then feeding another. Table III gives results obtained when the same scheme was applied to nitrile activated sludges. Acrylo-, lacto-, and oxydipropionitrile were resistant to the microbiota acclimated to the remaining three test nitriles in surface water. Activated sludge tests pointed toward resistance in the same three, but lactonitrile was exceptionally troublesome. Lactonitrile acclimated sludges could adapt readily to other nitriles, but the reverse required long periods of reacclimation. Behavior during the first week was the basis for judgment, as sludge age was about two to three days and new systems generally gave good performance in about two weeks. The second week was used for decision only when efficiency of the first was doubtful. Sludge age obviously did not indicate regeneration time for the slower growing organisms.

Microscopic Observations

Microscopic observations showed a wide variety of organisms common to activated sludge systems. Microbial species intolerance was not as great as anticipated. The variety of bacteria and predators generally showed almost as much variation from one week to

TABLE III. Activated Sludge Assimilation of a Different Nitrile Feed*

Nitrile Used for Acclimation	Nitrile Feed (approx. 100 mg/l)					
	Aceto-	Adipo-	Benzo-	Acrylo-	Lacto-	Oxydipropio-
Aceto-	—	Yes	—	Yes	No	Yes
Adipo-	—	—	—	—	No	Yes
Benzo-	—	Yes	—	Yes	No†	Yes
Acrylo-	Yes	Yes	Yes	—	No	Yes
Lacto-	Yes	—	Yes	Yes	—	Yes
Oxydipropio-	Yes	Yes	Yes	No†	No	—

* Yes indicates satisfactory adjustment within one week; no indicates unsatisfactory adjustment in one week.

† Doubtful during first week, based on the second.

another in a given nitrile sludge as it did from one nitrile culture to another. Certain limitations were observed as noted. Fungi were not detectable in activated sludge units except for the predacious fungus described by Cooke and Ludzack (6). Nitriles partially inhibited its growth. The limitation on fungi may account for the difference in cross-acclimation between surface water and activated sludge. Lactonitrile definitely inhibited protozoan populations and variety. A few stalked ciliates and small flagellates accounted for most of the predators in lactonitrile sludge. The bacterial floc in lactonitrile systems consisted of thin masses with many long rope-like projections. Cultures on tryptone glucose agar, that were selected and stained, indicated many varieties of bacteria, but no attempt was made to identify species or determine the precise number represented. Greater variety and numbers of both bacteria and predators were observed in other nitrile sludges. *Sphaerotilus* occasionally appeared in all nitrile test units and became troublesome at least once in all but lactonitrile units. Acetonitrile sludge floc was highly dispersed; oxydipropionitrile produced a dense growth with few projections, which is consistent with the sludge density noted.

Nitrates Problem

High nitrates were characteristic of nitrile acclimated sludge effluents. Increasing concern for the nitrate content of surface water may result in effluent limitations on nitrates. The load range permitting good nitrile treatment without high nitrates appears too narrow for practical purposes and would only delay nitrate production in the receiving water.

If nitrates are a problem, waste activated sludge denitrification offers a practical removal method. The technique of McKinney and Conway (7) was used for bench-scale tests. The unit in Figure 1 was modified by removal of the diffuser and by addition of a magnetic stirrer. High nitrate effluent entered at the bottom and discharged in the usual manner. A concentration of approximately 2,000 mg/l of waste sludge was maintained in suspension using the stirrer bar. Good contact of sludge and effluent was provided but agitation was not great enough to prevent clarification. The main problem was to provide sufficient agitation to dislodge gas bubbles from the solids so that they could settle. A light load of readily available food was necessary to increase oxygen requirements to slightly above that for endogeneous action. Oxygen was provided by surface contact, effluent DO, or the reserve in nitrites or nitrates. Careful control avoided the usual symptoms of anaerobiosis and resulted in 40- to 98-per cent removal of effluent oxidized nitrogen depending on sludge concentration, condition, and feed. Organic nitrogen in the contact effluent increased by 2 to 4 mg/l; ammonia remained about the same or decreased. Suspended solids in the denitrified effluent increased by 10 to 30 mg/l, but BOD rarely exceeded an increase of 10 mg/l. Sludge volatile solids decreased 5 to 10 per cent per day; hence, new waste solids were required frequently. Floating solids rarely caused difficulty with proper agitation. Contact time of 3 to 4 hr, including ½ hr for settling, was adequate. Denitrification in a stream is likely to remove appreciable quantities of oxidized nitrogen; this process could accelerate the removal when necessary.

General Considerations

Concentrations or load limits indicated in the preceding cannot be recommended, per se, as the maximum allowable because of the complexity and adaptability of activated sludge treatment. They are presented mainly as guidelines for consideration in new situations or tests and to provide background information on control of vari-

ables. Recirculation was not attempted, but may be desirable for treatment of highly concentrated wastes.

The more resistant nitriles exhibited a marked difference in acclimation time between surface water and activated sludge. Oxydipropionitrile required about 100 days before significant degradation occurred in surface water; it required from 5 to 10 days for similar degradation to be established in activated sludge. The number of organisms per unit volume is the major difference between the two. The results show that organisms suitable for assimilation of resistant chemicals are much more likely to be found in effective numbers in a high microbial population such as activated sludge.

Anaerobic Digestion Experimental Details

Tests were designed primarily to evaluate the effects of nitriles on the digestion of other organic materials in a mixed feed. This was deemed necessary because nitriles are quite soluble in water; distribution is more likely to favor a large fraction of the nitriles in the settler effluent than its accumulation in settled solids which eventually reach the digester. A relatively small fraction of the total nitrile in the feed could have a significant effect on digester operation if it were sufficiently toxic to digester organisms. The following discussion shows the results of these tests.

A 9-l digestion bottle was connected to an appropriate water-displacement gas holder. The units were started with sludge from a local sewage digester with an amount added that included 50 g of volatile sludge solids in each unit. A reference feed of 4 g of dry dog-food meal in sewage (250 ml) was added three times each week until equilibrium gas production per gram of added dog food was reached. The units were operated at 30°C and gas volumes measured at barometric pressure at the same temperature. Agitation was intermittent by swirling the bottle containing digesting solids. Continuous gas recirculation made little difference in gas yield per gram of feed; hence, was dropped.

Analysis of sludge solids was performed monthly for suspended and volatile solids. Solids were adjusted, if necessary, to maintain 50 to 75 g of volatile material in the unit. The added dog food resulted in 15 to 20 per cent of new volatile solids per week.

Gas produced was analyzed for carbon dioxide content and burned as necessary. Supernatant analysis (once weekly) included COD, ammonia and organic nitrogen, volatile acids (short procedure), and pH (3).

The gas production stabilized in three reference units at 600 to 650 ml of gas per gram of dog food added (90-per cent volatile). This ratio is within the range expected in municipal anaerobic digestion for equivalent volatile solids; hence, it does not appear that the batch feeding made a significant difference in operation.

The relatively light load of dog food solids should be similar in effect to the addition of a comparable amount of sludge volatile solids. Additional test loading should result in increased gas per gram of added dog food, provided the added test material is digested. It was assumed that a significant change in gas production would be the result of the added test nitrile.

Results of Anaerobic Digestion with Added Nitrile

Gas production and pertinent analytical data are given in Table IV on nitriles having little toxic action in the anaerobic system. Reference feed data are presented for comparison. Nitrile units received the same quantity of dog food as the reference, plus the nitrile dosage indicated in parenthesis under each heading. For example, under acetonitrile (40×14) indicates 40 mg/l of nitrile were added 14 times during the one month of operation.

TABLE IV.—Digester Characteristics with Nitrile Feeds

Characteristics for 1 Mo. Operation	Reference Feed Only	Reference Feed + Nitrile (mg/l nitrile added × number of doses)			
		Aceto- (40 × 14)	Adipo- (40 × 15)	Benzo- (40 × 15)	Oxydipropio- (40 × 14)
Mean gas prod. (ml/g dog food, 30°C)	620	560	570	600	560
% CO_2 in gas, range	26–29	27–32	21–29	26–29	23–30
pH range	6.8–7.2	6.9–7.1	6.7–7.1	6.7–6.9	6.9–7.1
Supernatant vol. acids (mg/l)	25	40	25	25	25
Supernatant COD range (mg/l)	800–950	1,100–1,900	860–1,700	1,000–2,200	1,200–2,400
Residual sludge vol. (%)	43	48	46	49	47

The concentrations were based on the total digester liquid volume.

It is obvious that the gas produced per gram of added dog food was somewhat less or equivalent in the nitrile systems than in the reference. This meant that the nitrile was not being converted to methane or carbon dioxide but that it did not exert significant toxicity in digestion of the reference feed. Confirmation of the stability of nitriles under test conditions was shown by the presence of infrared cyanogen absorbance bands in supernatant extracts up to three months after cessation of nitrile feeding.

Supernatant COD indicates a steady rise in oxygen demand with additional nitrile doses. It reached two or more times the value for the reference system in one month. Operation for another month failed to make a significant change in performance. These nitriles apparently will not disrupt gas production but they will not help it either.

Table V shows the results of acrylo- and lactonitrile, which had serious toxic action in anaerobic digestion. The higher doses of nitrile stopped gas production relatively quickly; lower doses required a little longer. Effect on the supernatant COD was more intense than that given in Table IV. The lower dosage of lactonitrile was given a different sequence from that in the remaining tests. Only one application on each Monday was given. After seven weeks' operation, the maxima of both volatile acids and COD had been reached and values were decreasing while gas production was increasing. This suggests that acclimation in an-

TABLE V.—Digester Characteristics with Nitrile Feeds

Characteristics for 1 Mo. Operation	Reference Feed Only	Reference Feed + Nitrile (mg/l conc. × number of doses)			
		Acrylo- (40 × 3)	Acrylo- (10 × 5)	Lacto- (40 × 1)	Lacto- (10 × 5)
Mean gas prod. (ml/g dog food, 30°C)	620	80	240	20	490
% CO_2 in gas, range	26–29	27–30	20–27	20	28–35
pH range	6.8–7.2	6.6–6.9*	6.6–7.1*	6.3–6.9*	6.6–6.8
Supernatant vol. acids, max (mg/l)	25	1,200	700	800	400
Supernatant COD range (mg/l)	800–950	1,000–4,600	1,100–3,000	2,000–4,400	1,300–2,400
Residual sludge vol. (%)	43	53	49	48	44

* Limed.

aerobic systems is possible but not interesting from a practical standpoint of view of the good removal by aerobic treatment.

Summary and Conclusions

1. Acclimation of activated sludge to tested nitriles requires a relatively short time to achieve a high degree of treatment.

2. Enzymatic hydrolysis to ammonia followed by nitrification appears similar to that in surface water.

3. Nitrile activated sludges appear quite resistant to shock loading and behave similarly to conventional systems in response to tested control variables and applied loading. Acrylonitrile sludges were more sensitive to changes.

4. Cross-acclimation of activated sludge to different nitriles indicates all but lactonitrile to be similar in breakdown characteristics.

5. Nitrate problems in the effluent are more likely to be handled successfully by effluent denitrification than by treatment control to prevent nitrification.

6. Performance of nitriles in anaerobic digestion does not recommend this method of treatment. Lacto- and acrylonitrile were definitely toxic to the digestion organisms.

7. Acclimation to resistant chemicals in a feed is accomplished much more rapidly in the presence of a high microbiological population such as activated sludge.

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34th ANNUAL MEETING

WATER POLLUTION CONTROL FEDERATION

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GRAPHICAL AND MATHEMATICAL INTERPRETATIONS FOR CHLORINE DETERMINATIONS

M. C. Rand, Joseph V. Hunter, and H. E. Orford

In the chlorination of wastewater, it is frequently necessary to perform laboratory tests for the purpose of determining the dosage of chlorine required to accomplish a given result. This result may be a certain coliform density, a stated reduction of biochemical oxygen demand, destruction of some chemical component of the wastewater, or some other predetermined objective. In terms of the old-fashioned "chlorine demand," the endpoint was the presence of a stated concentration of residual chlorine after a fixed time of contact.

In any of these tests, an attempt to find conditions which produce exactly the endpoint result is often a laborious procedure. A great many of the tests must be performed, using very small increments of chlorine dosage, to provide reasonable assurance that the endpoint will not be missed. Moreover, if the analysis used for determining the endpoint has a poor degree of precision, it is necessary to repeat the determinations on each chlorinated sample in order to observe the endpoint accurately. These factors tend to require large quantities of sample and of reagents, and a great deal of the analysts' time, which makes it an inefficient and expensive procedure.

The general method of adding a reagent in many small increments to permit direct observation of the quantity needed to reach the endpoint is well suited to certain determinations. Usually these involve reversible reactions, and the best application of this technique requires a system which gives an immediate or very simple indication of the endpoint condition. The ideal example, perhaps, is an acid-base titration, using an internal indicator or a glass electrode.

In the determination of chlorine requirements, however, the circumstances are very different. The reactions involved are irreversible, and, within the specified contact time, often incomplete. Thus, failure to realize exactly the endpoint result with a given dosage involves a new start with a new sample. Also, determination of the result produced by each dosage is relatively complicated. Various other determinations of this class might be cited, of which studies of the effect of adsorbents are perhaps most familiar.

In determinations of this type, there is an advantage in employing a different approach, designed to reduce the number of reagent dosages and subsequent determinations of results. Using a limited number of dosages, including dosages both above and below that required to produce the desired result, the dosage corresponding to the desired endpoint may be determined by graphi-

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cal or mathematical means. An appreciable saving of time and reagents results, and with reasonable precautions there is little or no loss of accuracy.

The Graphical Method

In the graphical method, the results produced by various reagent dosages are plotted against the corresponding dosages. A curve is then drawn through the points, and the dosage corresponding to the endpoint result is taken from the graph. Although this procedure offers an appreciable saving of time over attempting to actually observe the desired result, it does introduce the possibility of some subjectivity in the interpretation, and some time is required for the plotting of the curves.

When the points tend to scatter rather than form a smooth curve, the graphical method is not applicable. However, in such cases, any other method, including direct observation of the endpoint, is equally inaccurate. Such situations call for better analytical methods or replication of analyses, to decrease the uncertainty of the observed results.

Mathematical Methods

The possibility of subjective bias can be eliminated from the interpretation if the plotting of the results is replaced by completely objective mathematical treatment of the data. This may be done by a number of different methods none of which require construction of a graph.

Least Squares

It is possible, by standard statistical formulas, to calculate the line or curve which best fits the data, and then to calculate the dosage at which the line or curve crosses the desired result. This may be done without actually constructing the graph. However, it requires more time than the graphical method, and when only a limited number of points is available, there is no significant improvement of precision.

First Approximations

A much more rapid, but slightly less accurate, calculation of the dosage required to produce the desired result may be obtained by linear extrapolation or interpolation from the observed points. If results are determined at two dosages lying on the same side of the requirement, linear extrapolation to the desired result may be used to approximate the corresponding dosage. Alternatively, if results are determined at two dosages of which one is above the "endpoint" dosage and the other is below, linear interpolation may be used to find an approximation of the endpoint dosage.

However, in many cases, and almost always in chlorination, the relationship between dosage and result describes a curve rather than a straight line. When this is the case, either interpolation or extrapolation used alone introduces a systematic error in the final answer. Figure 1 demonstrates this effect. An extrapolated line always intercepts the "desired result"

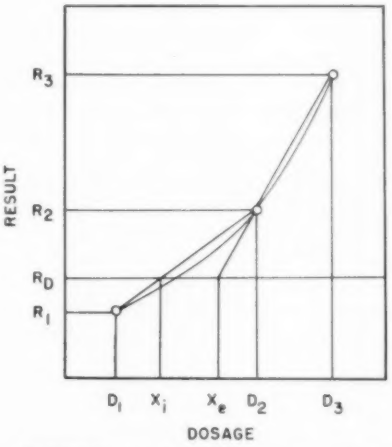

FIGURE 1.—Typical curvilinear relationship between dosage and result which can be subjected to mathematical interpolation.

on the convex side of the curve, while an interpolated line always crosses the "desired result" line on the concave side of the curve. In Figure 1, where the curve shown is concave upward and to the left, this means that extrapolation will always give a value higher than the true dosage requirement, and interpolation will always produce a value lower than the true value.

The Second Approximation

Since one of the two methods described for obtaining a first approximation of the required dosage produces results which are consistently too high, and the other results which are consistently too low, it follows that neither is a completely satisfactory means of determining the dosage requirement. By combining the two methods, however, the tendency toward systematic errors can be eliminated. At the same time, there is a slight improvement in the precision of the final result, since a larger number of observed points is used in its calculation. Since the true requirement lies somewhere between the extrapolated value and the interpolated value, any method of selecting a point intermediate between the two gives an answer which is more accurate than either of the first approximations. For practical purposes, the simplest procedure is to select the point midway between the two first approximation values.

Referring again to Figure 1, the formulas for applying the second approximation method are developed as follows:

Let D_1, D_2, and D_3 represent the dosages actually used, and let R_1, R_2, and R_3 represent the corresponding results. It is necessary that D_1 be a dosage insufficient to produce the desired result, and that D_3 produce a result beyond that desired. Dosage D_2 is intermediate between D_1 and D_3. In Figure 1, D_2 is greater than the required dosage, but it will be shown later that D_2 may have any value between D_1 and D_3. Let R_D represent the numerical value of the desired result, and let X represent the corresponding required dosage. Extrapolation from the two observed points D_2, R_2, and D_3, R_3 gives a value of X which may be designated as

$$X_e = D_2 - \frac{(D_3 - D_2)(R_2 - R_D)}{R_3 - R_2} \quad \ldots (1)$$

By interpolation from points D_1, R_1, and D_2, R_2, another value of X is obtained, which is called X_i.

$$X_i = D_2 - \left[(D_2 - D_1) \frac{R_2 - R_D}{R_2 - R_1} \right] \quad (2)$$

For the second approximation of X, the point midway between X_i and X_e is found easily by the formula:

$$X_2 = \frac{X_i + X_e}{2} \quad \ldots (3)$$

There is no need to construct a graph comparable to Figure 1. The formulae may be applied directly to the observed data.

Exactly the same formulas apply if D_2 is less than X. In this case, R_2 will be less than R_D. The only difference is that the factor $R_2 - R_D$, which appears in both Equations 1 and 2, will then be negative. This makes the second term of each equation positive, to give values of X_i and X_e which are greater than D_2. Also, in this case, Equation 1 will give an interpolated value of X, and Equation 2 an extrapolated value. The final result will be unchanged.

Experimental Testing

Data demonstrating the practical application of the graphical method and the second approximation method appear in Tables I, II, and III. The data actually represent "chlorine demand" values of a strong industrial waste. In other words, the desired result in this case was the presence of a specified concentration of residual

TABLE I.—Comparison of Chlorine Demands of an Industrial Waste Obtained by Amperometric Titration as Calculated by Graphical and Mathematical Interpolation

Sample No.	Chlorine Demand (mg/l)		
	Mathematical	Graphical	Difference
1	74	73	1
2	129	128	1
3	127	123	4
4	58	56	2
5	96	97	1
6	57	58	1
7	113	117	4
8	111	104	7
9	80	82	2
10	85	92	7
11	89	91	2
12	64	68	4
13	85	88	3
14	76	74	2
15	101	95	6
16	59	54	5
17	72	75	3
18	44	43	1
19	54	53	1
20	76	82	6

chlorine after a given contact time. Tables I and II show corresponding values obtained by the graphical method and the mathematical second approximation in 30 different determinations. The two tables present data obtained by two different methods of analysis for residual chlorine. No comparison between analytical methods is intended. In the 30 sets of results presented in the two tables, the mathematical result was the higher in 17 cases and the graphical result was higher in 13. This indicates no tendency toward a consistent or systematic difference in either direction. Statistical analysis of the data gives 3.2 per cent as the probable difference between an answer obtained mathematically and the corresponding graphically computed answer. This is of about the order of magnitude of the precision of measuring the chlorine dosage applied, and hence is within the confidence limit of any result, including that obtained by actual observation of the desired result.

TABLE II.—Comparison of Chlorine Demands of an Industrial Waste Obtained by O.T. Method as Calculated by Graphical and Mathematical Interpolation

Sample No.	Chlorine Demand (mg/l)		
	Mathematical	Graphical	Difference
1	177	172	5
2	117	115	2
3	160	156	4
4	233	211	11
5	236	225	11
6	248	250	2
7	231	223	8
8	301	294	7
9	261	264	3
10	251	254	3

Table III presents the data of another set of determinations, in which sufficient numbers of dosages were used to permit actual observation of the de-

TABLE III.—Comparison of Chlorine Demands of an Industrial Waste Obtained by Either Amperometric Titration or O.T. Method, as Actually Observed at a Residual of 0.1 mg/l of Cl_2, and by Graphical and Mathematical Interpretation

Sample No.	Method for Residual	Chlorine Demand (mg/l)			Per Cent Variation*	
		Observed	Mathematical	Graphical	Mathematical	Graphical
1	Amp. titr.	100	96	97	4.0	3.0
2	Amp. titr.	120	113	117	5.8	2.5
3	Amp. titr.	84	80	82	4.8	2.4
4	O.T.	238	236	225	0.8	5.5
5	O.T.	230	233	221	1.3	3.9
6	O.T.	225	231	223	2.7	0.9

* From observed value.

sired residual concentration of chlorine. The data are limited because of the time and sample volumes consumed in this procedure. Accordingly, the precision of statistical constants obtained from the data is not extremely good, but the data show that the variation of either indirect method from the value obtained by direct observation is about the same as the variation between the two methods. Again, considering the accuracy with which the dosage of chlorine is known, it is apparent that for a given determination, any one of the three values presented is equally likely to represent the true value of the chlorine demand.

Summary

Determining the chlorine dosage required to produce a given result by attempting to actually observe that result is a laborious and expensive procedure. If, however, the results produced by three or more dosages bracketing the required dosage are observed, the required dosage may be derived by either graphical or mathematical means. Since the accuracy of the answers so obtained is as good as the accuracy of measuring the dosages and their effects, it is comparable to that realized by direct observation. While there is no significant loss of accuracy, a great increase of efficiency is realized, through savings of time, reagents, and sample volumes.

The mathematical second approximation requires slightly less time than the graphical method, and has the advantage of giving a completely objective interpretation of the data.

SEWER BOND SALES AND INTEREST

Date	Sewer Bond Sales ($ million)	Net Interest Cost of Sewer Bonds (per cent)	
		General Obligation	Revenue
1960			
Jan.	35.3	4.10	4.68
Feb.	37.2	3.65	3.98
Mar.	21.7	3.65	4.90
Apr.	43.2	3.70	3.90
May	23.2	3.79	4.53
June	36.7	3.91	4.09
July	55.5	3.74	—
Aug.	39.2	3.27	4.10
Sept.	30.3	3.42	3.77
Oct.	16.4	3.28	4.79
Nov.	26.3	3.33	4.01
Dec.	24.1	3.41	4.11
1961			
Jan.	41.1	3.48	4.41

Data from WSPC Public Health Service.

WASTE CONTROL AT THE HANFORD PLUTONIUM PRODUCTION PLANT

R. F. Foster, R. L. Junkins, and C. E. Linderoth

The atomic energy installation at Hanford is comprised of a complex of process and research operations established in nine widely separated sites on a 567-sq mile reservation in southeastern Washington. The general orientation of the plant is shown in Figure 1. This area, which consists almost entirely of sagebrush desert, was chosen as the site for the plutonium production reactors because of the few settlers which would have to be displaced, the abundance of high-quality water from the Columbia River, an adequacy of power from hydroelectric dams, and favorable terrain. The site was also admirably suited for the control of large quantities of radioactive waste.

The precise locations of the different facilities associated with various process steps were selected to make optimum use of the topography. The basic steps in the process include: (*a*) preparation of uranium-metal fuel elements, (*b*) irradiation of the uranium in the nuclear chain reactors so that a part is transmuted into plutonium, and (*c*) dissolution of the fuel elements followed by chemical separation and purification of the plutonium. The unaltered uranium is also recovered for reuse. In addition to these manufacturing functions, Hanford is the site of extensive research operations which contribute not only advanced concepts and technology associated with the various processes but also provide basic information on the handling and control of wastes and on the many aspects of safeguarding workers and the public at large from overexposure to radioactive materials.

The potential radiation hazard associated with preparation of the fuel elements and with most of the research laboratories is small and these facilities are conveniently located at the southern edge of the reservation close to the city of Richland. The reactors are placed close to the river, which supplies the water needed for cooling. Because some of them were the first high-power reactors ever built and they were placed in operation when reactor technology was a new art, they were located some distance from population centers. The chemical separation plants, which use far less water than the reactors, are placed inland on a low plateau where ground conditions are most favorable for containment of radioactive liquid wastes. Several of the aspects of radioactive waste disposal at Hanford have been described by Rostenbach (1).

Nature and Disposition of Waste

Virtually all of the radionuclides which are eventually present in the wastes are created in the reactors. Two different mechanisms are involved in their formation, but these occur coincidentally. One mechanism is the

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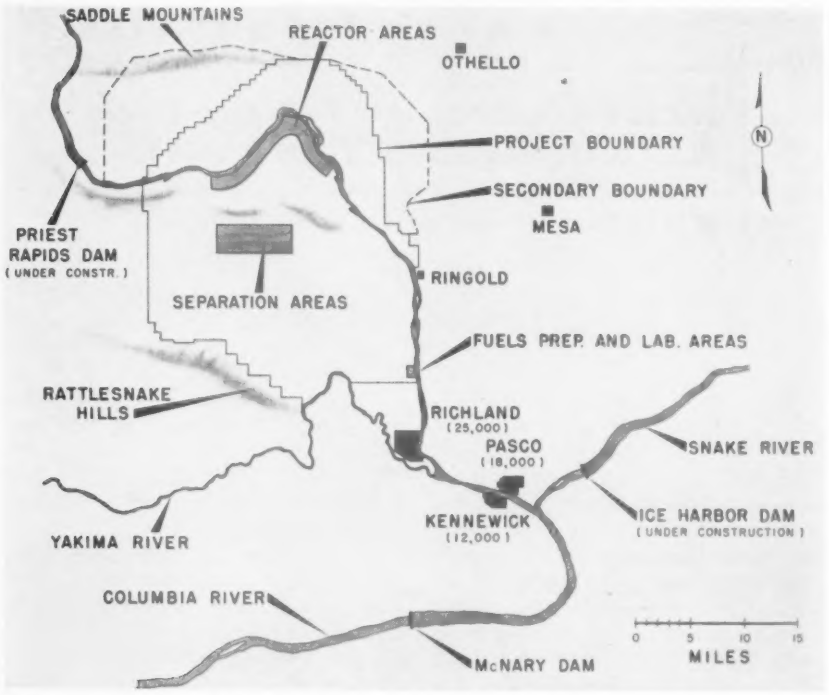

FIGURE 1.—Hanford plant environs.

formation of fission-products within the fuel elements as the atoms of uranium-235 are split by neutrons ejected by other uranium atoms. The fission products accumulate in the elements as the fuel is expended and, because they act as poisons to the chain reactions, contribute to the need for replacement of the fuel in the reactors. Under normal circumstances the fission products do not escape from the fuel elements until they are dissolved in the chemical separations plants. At that point, however, they constitute a major handling and disposal problem.

Not all of the neutrons produced in the fission process are involved in sustaining the chain reaction. Some of them are captured by the common isotope of uranium-238, which leads to the creation of the new energy source, plutonium-239. Other neutrons escape the fuel elements and are absorbed by materials within the reactor such as the control rods, the piping, the coolant, the atmosphere, and the surrounding shields. As a result of the neutron bombardment, all of these materials become radioactive; this is the second mechanism which creates radioactive wastes.

When the fuel elements are removed from the reactor or the reactor is shut down, essentially no additional radioactive material is created. Once formed, however, there is no way by which the radioactive substances can be "deactivated" save through the built-in radioactive decay process itself. Dependent on the particular nuclide involved, this may be accomplished in fractions of seconds or only after thousands of years. Nevertheless, the radioactive materials are isotopes of chemical elements and, with proper radiological precautions, they can be

manipulated in the same manner as the non-radioactive isotopes of the same elements. They can be placed in solution, combined into compounds, concentrated, precipitated, diluted, or volatilized. Unlike the neutrons of the reactor, however, the radioactive wastes cannot change the atoms of other materials into radionuclides. On the other hand, because of their chemical properties, they may cling to the surfaces of things which they touch with such tenacity that great effort is needed to dislodge them. Equipment which has become contaminated through contact with a radioactive substance may, therefore, need to be disposed of as a type of radioactive waste.

The basic objectives in the management of the radioactive wastes are: (*a*) concentration of high-level wastes and long-term storage while the process of radioactive decay gradually reduces their potency, (*b*) retention of intermediate-level wastes in the ground in such a manner that radionuclides of significance do not enter the environment, and (*c*) dilution of low-level wastes with air or water to such an extent that they do not constitute a hazard in the environment. The varied process and research operations at Hanford generate radioactive wastes which are indicated schematically in Figure 2. Those which are handled as liquids and which require extensive management are emphasized here.

Fuel Preparation

Natural uranium in a highly purified state is supplied to Hanford in the form of metal cylinders. Local preparation of the fuel elements includes bonding of an aluminum jacket to the uranium and rigorous testing to guard against failure of the jacket when the element is placed in a reactor. The wastes which arise from jacketing and testing of the elements are typical of those encountered in metal processing industries and consist mostly of cooling water, pickling rinses, and dilute caustics. Although the uranium is naturally radioactive

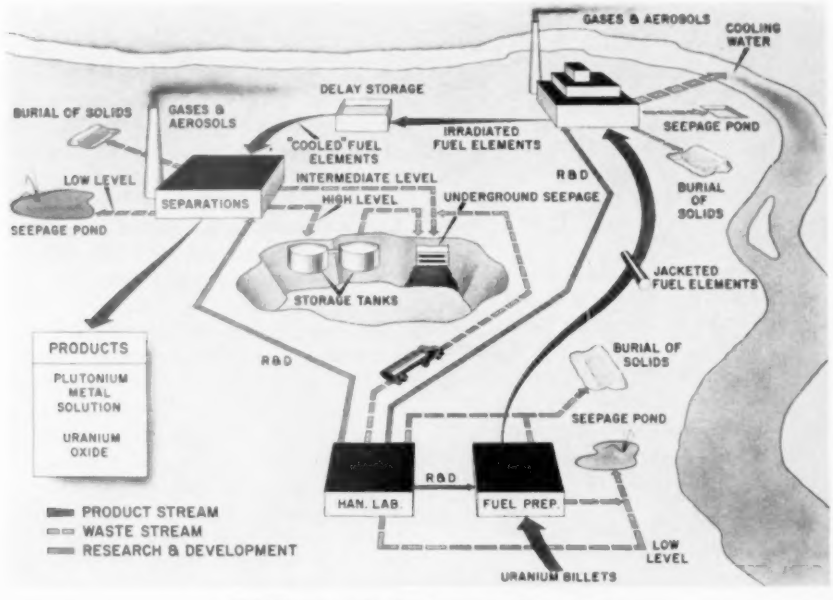

FIGURE 2.—Hanford process flow chart.

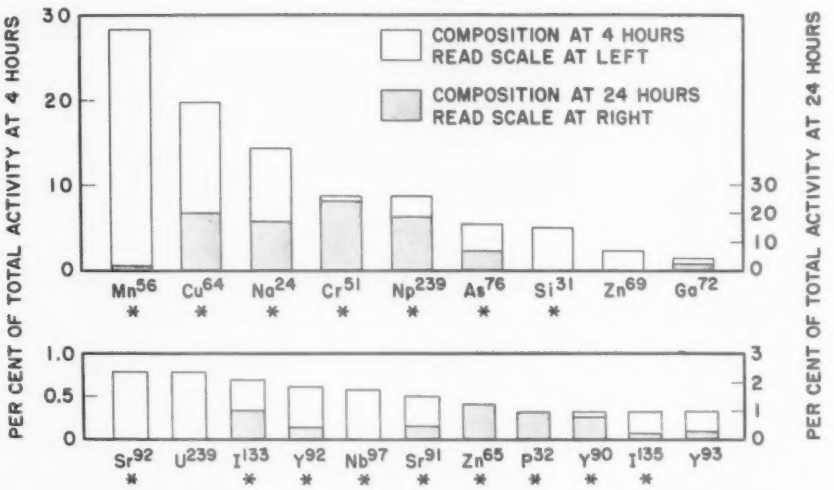

FIGURE 3.—Radioelement content of reactor effluent 4 hr and 24 hr after irradiation. (Radioelements marked * are routinely measured.)

and must be handled with respect, the waste disposal problems associated with this operation are minor in comparison with those encountered following irradiation of the uranium in the reactors.

The waste solutions resulting from the fabrication of the fuel elements contain only low concentrations of uranium and are discharged to either of two settling ponds located a few hundred feet back from the Columbia River. These ponds also receive low-level uranium wastes from some of the research laboratories. These wastes slowly percolate down to the water table beneath the ponds and eventually seep into the Columbia River. The concentration of uranium in the pond water averages about 5×10^{-7} μc/ml, a level which would be quite acceptable in drinking water.* Uranium is a natural constituent of Columbia River water and is normally found at a concentration of about 2×10^{-9} μc/ml. Close to the settling ponds the concentration of uranium in river water is nearly twice the natural amount (3), but the contribution from the ponds is diluted to such an extent that it cannot be distinguished from the natural amount beyond a mile downstream.

Reactor Operation

The splitting of the uranium atoms in the reactors releases a large amount of energy, which heats up the fuel elements and the matrix of the reactors. To avoid thermal damage, this heat is continuously removed by copious amounts of water pumped through the channels which contain the fuel elements.

The cooling water is drawn from the Columbia River, but before use in the reactor it is purified by conventional methods consisting of alum flocculation, settling, and filtration through anthracite and sand. Adjustment of the pH and addition of sodium dichromate complete the treatment. The cooling water makes but a single, brief pass through the reactor—no recirculation loops or heat exchangers are used.

As the cooling water, or effluent,

* The maximum permissible concentration of natural uranium in drinking water recommended for occupational exposure by the National Committee on Radiation Protection is 2×10^{-4} μc/ml (2).

leaves the reactor it is quite hot and contains radioactive materials. Some of these radioactive materials are the result of neutrons striking materials normally present in solution in the cooling water; some result from the corrosion of reactor piping that has been subject to neutron bombardment; and some result from the fissioning of natural uranium present in river water. In a general way, the radioactivity of the effluent can be viewed as originating from impurities in the water which have been made radioactive during their trip through the reactor. More than 60 radionuclides have been identified in the effluent. Because each of these has a different rate of radioactive decay, their relative abundance is constantly changing. The comparative concentrations of the nuclides which make up most of the radioactivity at 4 hr and at 24 hr are shown in Figure 3. The nuclides with very short half-lives, such as Mn^{56}, Zn^{69}, Sr^{92}, U^{239}, and Nb^{97}, have virtually disappeared by the end of the first day; whereas, those with longer lives, such as Cr^{51}, Np^{239}, Zn^{65}, and P^{32}, have decayed only slightly during this time and assume a more dominant position.

Although the presence of the reactor-produced radionuclides demands that the effluent be managed as a radioactive waste, the actual concentrations of the nuclides are quite low under normal operating conditions. The concentrations are, in fact, so low that no single nuclide is present at a concentration which exceeds the maximum permissible concentration for drinking water for occupational workers (2). The effluent is not, of course, of drinking water quality inasmuch as a mixture of many nuclides is involved and their additive effects must be taken into account. Because of the low concentrations and large volumes involved, it is not practical to scavenge the radioactive materials from the effluent by conventional methods. In this case, however, the capability of greatly diluting the effluent is at hand because the flow in this section of the Columbia River is seldom less than 50,000 cfs, and is several times greater during the spring and early summer months. Although the calculated dilution would indicate that the Columbia River water downstream would be quite safe for use as domestic supplies, a substantial amount of research and monitoring effort has been expended to provide assurance that this is indeed the case and that the river water is also safe for other users. This aspect is treated in more detail in a following section.

Prior to release in the river via submerged pipes, the effluent is retained briefly in basins or tanks. This retention allows some radioactive decay of short-lived radionuclides—enough to reduce the gross radioactivity of the effluent by 50 to 70 per cent. It also provides an opportunity for diversion of off-standard effluent (on rare occasions it is desirable to direct effluent having an unusually high radioactive content into trenches, where it seeps into the ground).

Off-standard effluent can result from a break or perforation in the aluminum jacket of a fuel element allowing the fission products to enter the water. A single small break may more than double the gross radioactivity of the effluent leaving a reactor, especially increasing the concentrations of the longer-lived nuclides. As soon as a break is detected, the reactor is shut down and the offending fuel element is replaced.

The flow of cooling water through a typical reactor area and its return to the river as effluent is shown schematically in Figure 4. In addition to the liquid effluent, there are two minor sources of radioactive waste from the reactors. One is the air used for ventilation, which is continuously exhausted to the atmosphere through a stack. This air picks up contaminated dust from portions of the reactor building which are normally unoccupied, to-

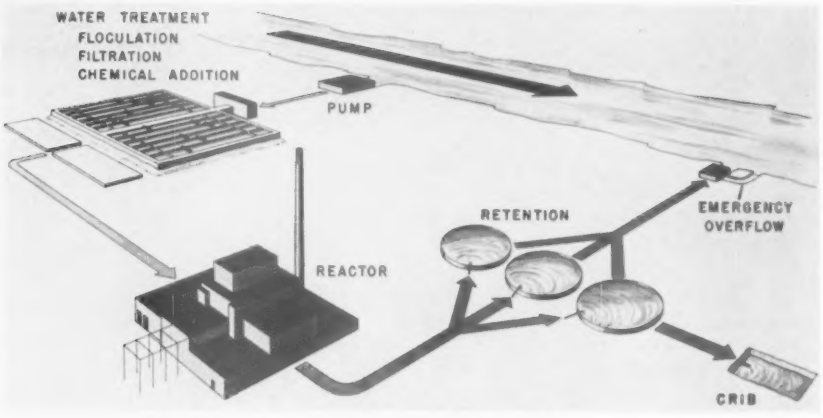

FIGURE 4.—Water flow through a typical reactor area.

gether with any gas which leaks from the reactor chassis. Only in the event of a serious and highly improbable accident would this exhausted air lead to significant contamination beyond the project boundaries. As an added precaution, however, fog-spray equipment backed up with "CWS Absolute"-type filters are now being installed to limit the escape of small particles.

The remaining type of waste worth mentioning is the solids that have become radioactive either as a result of neutron activation within the reactor or because of contamination through contact with materials that have been used in the reactor. Involved are such things as aluminum spacers used to center the charge of fuel elements, parts of the reactor hardware which have to be replaced, paper, boards, rags, worn-out tools, and the like. These solids are buried in shallow trenches above the level of the ground water. Leaching of radioactive materials from them is negligible, as moisture from the limited rainfall penetrates only a few feet. Similar solid wastes are buried in a like manner at all of the process areas.

Chemical Separation

Processing of the highly radioactive fuel elements after their discharge from the reactors must be carried out by remote control. The elements are first placed in stainless steel tanks where the aluminum jackets are dissolved with a sodium nitrate and caustic solution. The uranium, together with its associated fission products and plutonium, is then dissolved in nitric acid and the resulting solution is piped through a solvent extraction process. The end products of the process are: (*a*) a plutonium concentration which is refined for future use as a nuclear energy source, (*b*) a uranium oxide which can be shipped off-site for reduction to metal and eventual reuse in the reactors, and (*c*) a highly radioactive liquid waste which contains the fission products. This waste contains large amounts of such long-lived radionuclides as Sr^{90}, Cs^{137}, Pm^{147}, Ru^{106}, and Ce^{144}, and is too hazardous to disperse in the environment. In great contrast to the reactor effluent, not even one gallon per day of this high-level waste could be disposed of to the Columbia River without exceeding maximum permissible concentrations.

Permanent Containment

At present, permanent containment is the only satisfactory method of handling the high-level waste. This is accomplished in steel-lined concrete tanks

buried a few feet underground. Each tank has a capacity of 0.5 to 1 mil gal and the total volume of waste accumulated to date is approximately 52 mil gal. To conserve tank space, the quantities of liquids used in the process are kept at a minimum, process water is reused insofar as practical, and the volume of the waste is reduced by evaporation prior to storage.

An appreciable amount of heat is liberated as the radionuclides decay. This causes the temperature of the wastes stored in the tanks to rise gradually until the liquid begins to boil. This boiling is deliberately used as a means of further reducing the volume of the waste and thus the recovery of space in the tanks. The concentrations in the tanks are actually so high that the wastes are in the form of slurries rather than solutions. Sludge-like deposits several feet thick exist in some tanks.

Although the great bulk of the fission products can be directed to the storage tanks, it is neither technically practical, nor necessary for radiological aspects, to remove every trace of radioactive material from the process solutions. To do so would require virtually 100-per cent efficiency on the recovery of more than 80 elements of widely different chemical characteristics from large volumes of a complex chemical mixture, a chemical engineering feat considerably beyond economic practicability by present-day technology (4).

Ground Disposal

Liquid wastes of an "intermediate" level of radioactivity include the condensed vapors arising from the evaporation of the higher-level wastes, solutions used in later steps of the separations process to complete the decontamination of the plutonium and uranium, aged solutions of high-level wastes from which the remaining long-lived isotopes have been scavenged, and some process steam condensate. The volume of this intermediate waste is on the order of 0.8 mgd and its concentration of radioactive materials generally is in the range of 10^{-5} to 100 μc/ml. Although far less radioactive than the high-level waste stored in the tanks, the intermediate waste is not suitable for dissipation in the environment. An approximate comparison can again be made to the reactor effluent based on drinking water standards. With the allowance of one day for decay of the short-lived nuclides present in the reactor effluent, one gallon of typical intermediate waste would be equivalent in radiological hazard to about one million gallons of the reactor effluent.

Through careful control it has been possible to dispose of the intermediate waste to the ground. In a very real sense this action is not disposal but ground storage, inasmuch as the method utilizes the capacity of the clay fraction of the soil to retain the radioactive contaminants through ion exchange, adsorption, and hold-up in pore spaces. The principal method of introducing the waste into the ground is through porous beds of graded gravel, which effectively distribute the waste over the desired area. These structures, called "cribs" or "caverns," are placed a few feet below grade and precautions are taken to prevent the waste from seeping up to the surface of the ground. Before reaching the water table, some 200 to 300 ft below the surface, the significant nuclides in the waste liquid are effectively retained in the glaciofluviatile sediments through which the liquid has slowly percolated.

Occasionally, isolated batches of waste are generated with chemical characteristics that would interfere with the desired ion exchange reaction normally available in the ground beneath the cribs. Such "incompatible" wastes are piped to open trenches, which are immediately back-filled to prevent dissemination of surface contamination by winds.

Since the plants were put into opera-

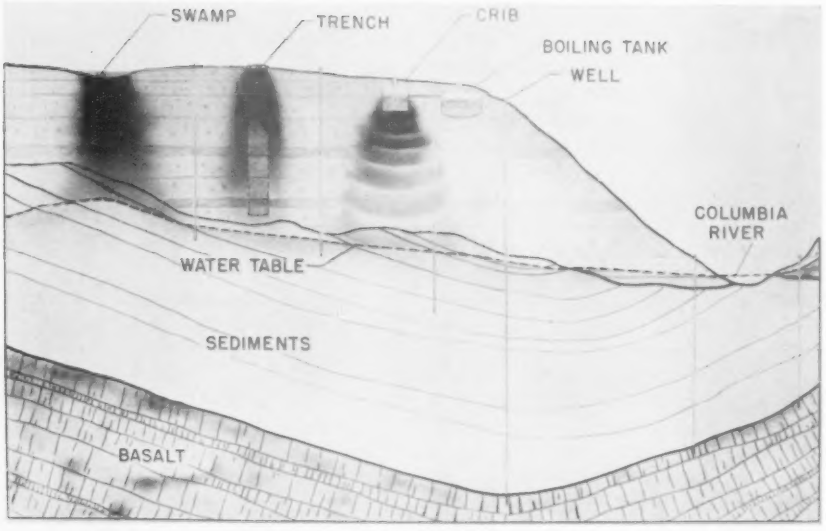

FIGURE 5.—Hanford site cross-section schematic showing waste disposal facilities.

tion in 1944, more than 4 bil gal of intermediate-level waste have been sent to cribs and trenches. The cost of disposal to cribs has been from $0.001 to $0.003 per gal and to trenches about $0.03 to $0.05 per gal. Such large volumes could not have been economically stored in tanks. It should be stressed, however, that the continued practice of ground disposal with safety has been made possible through concerted research and monitoring effort.

The volumes of waste sent to tanks or cribs represent but a small fraction of the water pumped to the separations plants each day from the Columbia River. A major fraction of the imported water is used for utility purposes or in process functions where it does not normally become significantly contaminated with radioactive materials. This wastewater, which amounts to some 12 mgd, is discharged into surface depressions where it forms shallow ponds or swamps. This water is handled as a low-level radioactive waste, however, because minor leaks in process piping result in low-level contamination.

The water discharged into the surface ponds seeps into the ground and eventually reaches the water table. Continuous use of the ponds for some 15 years has created an artificial mound of water on top of the original water table under each of the two separations areas. The western mound is in fine sand and clay, and its top now stands some 75 ft above the original water table. The eastern mound is situated in an area characterized by sand and gravel and its top is about 20 ft high. The natural hydraulic gradient of the ground water has been substantially modified by these mounds. Although the eastern mound may tend to constrain the movement of wastes toward the Columbia River, no reliance is placed on this transitory feature. The principal topographical features of this liquid waste disposal complex are shown in Figure 5.

Air-Borne Waste

For completeness, one other radioactive waste originating in the separations process must be mentioned. This is air-borne and its principal source is

the tanks in which the fuel elements are dissolved. As the metal is put in solution, various radioactive gases (such as radio-xenon) are released, vapors (such as radio-iodine) are generated, and entrained radioactive particles (including those of radio-ruthenium) are carried away. Later steps in the process add more of these same materials to the process air. Before release through 200-ft stacks, the radioactive contaminants are removed with a high degree of efficiency by beds of porous material impregnated with silver nitrate, by caustic scrubbers, and by filters. Experience has shown that the residual I^{131} leaving the stack is the most important reference on which to base day-by-day control.

Bases of the Waste Management Program

The waste disposal policy for the Hanford plant, as stated by Parker (5), is ". . . to limit the exposure of individuals and other significant life forms to the lowest practicable level." He further points out that, "The local standards are not less conservative than those prescribed by the Atomic Energy Commission and are broadly responsive to those promulgated by other qualified sources such as the National Committee on Radiation Protection and Measurement, and the International Commission on Radiological Protection. Particularly in matters concerned with releases of radioactive material to the environment, the posture has been conservative. Due to local research, limits substantially more restrictive than those to be inferred from conventional sources have frequently been developed."

The objectives of the program are attained through substantial effort in six general areas, as follows:

1. Limiting the quantities of radioactive materials which are released to the environment.

2. Determining, from laboratory studies, the capacity of soils and other ion-exchange media for retention of radioactive materials.

3. Tracking the released material as it moves through, or is dispersed in the receiving mediums or as it follows a variety of pathways which may bring it in contact with man.

4. Monitoring those substances, including foodstuffs, which may contribute to the radiation exposure of people living in the vicinity of the plant.

5. Comparing the quantities of particular radionuclides detected in local inhabitants with amounts observed in people from other regions.

6. Determining, through laboratory studies, maximum permissible concentrations of the wastes in the environment for the protection of domestic animals, fish, wildlife, and crops.

The diversified nature of these areas points up the importance of close association of research and development with routine plant operations. Only through a broad and integrated program of this kind has it been possible for a major-sized plant employing radically new concepts to handle with assurance of safety its large volume of waste of unprecedented characteristics.

Limiting Release to the Environment

Reactor Effluent

Because the high- and intermediate-level wastes arising in the chemical separations plants are effectively contained, the reactor effluent is the dominant source of radioactive materials released to the environment. Short of a recirculating loop with heat exchanger to isolate the neutron-irradiated water from the river water, there are three general methods which appear to have appreciable potential for minimizing the quantity of radionuclides released to the river. One of these involves identification and subsequent reduction of the specific substances in the coolant which are transmuted into radionuclides of importance. Another method

involves the use of chemicals to minimize the holdup and thus the irradiation time of the parent nuclides which cling to the surfaces of the reactor tubes. A third method involves selective retention of some radioisotopes for a sufficiently long period to allow substantial radioactive decay. Preliminary studies in these areas are encouraging and a more concerted research effort along these lines is now in progress.

Because the fission process is the basic source of neutrons needed for plutonium production and, in the case of power production, is the basic source of energy, the formation of fission products in the fuel elements is inescapable. A major research and engineering effort has been directed toward confinement of the fission products which are produced so that minimum amounts reach the environment. The first opportunity for such confinement is with the jackets of the fuel elements, as jacket failure within the reactors permits fission products to enter the coolant and eventually the Columbia River. A continuing program for development of superior fuel elements during the last several years has resulted in a substantial reduction in the percentage of jacket failures.

Chemical Separations Plants

Inasmuch as practically all of the fission products appear in the wastes of the chemical separations plants, a major part of the research effort and facilities devoted to waste control is associated with these plants. Further, as pointed out by Tomlinson (6), "... operations have always been planned on the premise that [release of a significant quantity of fission products to the environment] must not occur." Storage of the high-level wastes in tanks is the first phase in the confinement program. It is recognized that these tanks will eventually deteriorate and that this may occur before the radioactivity of their contents has decayed to non-hazardous levels; estimates of the useful lifetime of a tank range from a few decades to several hundred years. Should a leak occur it would be evidenced by an unanticipated drop in the liquid level in a tank and by the appearance of radioactive contaminants in monitoring wells nearby. In the event that a leak develops, facilities have been provided for the prompt transfer of the waste to another tank. Additional factors of safety are: (*a*) the some 200 ft of dry sediments beneath the tanks and above the water table which would retain the liquid from a modest leak, and (*b*) the fact that a substantial part of the radioactive material is associated with the heavy sludge which would tend to seal the leak rather than move through the ground.

It is generally recognized that indefinite storage of high-level liquid wastes in tanks is not an ultimate solution. Processes for economically converting the liquid wastes into solids or otherwise "fixing" them to achieve positive containment are being investigated at Hanford as well as at other sites.

Proper limitation of the quantity of intermediate-level waste discharged to ground at particular crib sites requires the evaluation of extensive physical and chemical information on both the waste and the disposal area. Premature abandonment of a particular discharge point entails unnecessary expenditure of funds at new locations. On the other hand, excessive use of the same site could result in undesirable contamination of the ground water. Both laboratory tests and field observations are employed to achieve optimum use of ground disposal facilities.

The mechanisms involved in the retention of the nuclides by soil particles are strongly influenced by the chemical composition of wastes. These mechanisms are studied in the laboratory in order to evaluate radionuclide removal efficiency and to determine the desirability of further treatment of the waste

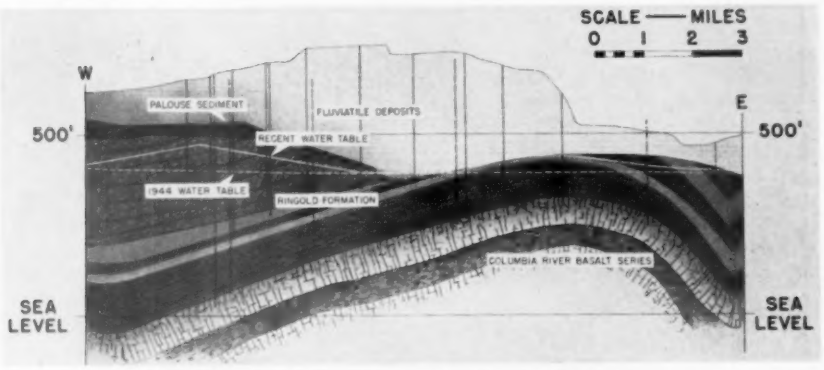

FIGURE 6.—Geologic cross-section of Hanford Works area.

to improve nuclide retention by the soils. Account must also be taken of the fact that the soils at different disposal areas may vary widely in grain size, mineral composition, and ion-exchange capacity.

All of the different radioelements in the wastes are not fixed to the soil particles with equal binding force. Those which are loosely held tend to move through the ground; whereas, those which are tightly bound remain near the point of discharge. The addition of chemicals which might mobilize the waste by weakening the bonds between the radioactive ions and the soil structure is avoided. Radiostrontium and radiocesium are most effectively fixed in the soil if introduced in an alkaline solution. Radioruthenium (Ru^{106}), an abundant fission product with a half-life of one year, usually occurs in the waste as a neutral molecule or an anion. In this form the ruthenium is not well fixed on the soil and travels nearly as fast as the water vehicle. Because of its comparatively high mobility through the soil beneath the crib sites, ruthenium is usually the first radionuclide to reach the water table. Its detection in monitoring wells adjacent to the cribs heralds the approach of the more hazardous isotopes. Use of a particular disposal facility is discontinued when radionuclides with half-lives of more than three years are detected in the ground water in amounts approximating one-tenth of the maximum concentration permitted for occupational exposure (2).

Tracking the Released Material

Ground Disposal

Liquid waste which has entered the water table beneath a disposal site will be transported in the ground water and may ultimately reach surface waters. Determination of the most probable place, time, and concentration at which the radioactive contaminants may reappear represents a substantial technological challenge and has entailed a major research effort at the Hanford site. Some 565 wells with a combined depth of more than 21 miles have been driven into the sediments of the area. Of these, 340 reach to the water table and 80 penetrate to the thick layer of basalt which underlies the region. Basic data from this extensive probing have been carefully evaluated to provide a reasonably accurate picture of the geology and hydrology of the region and a concept of the direction and rate of flow of the ground water.

A typical geological cross-section is shown in Figure 6. A layer of basalt several thousand feet thick forms the bedrock and its ridges are responsible for the hills and mountain features of the region (7). Because the ground

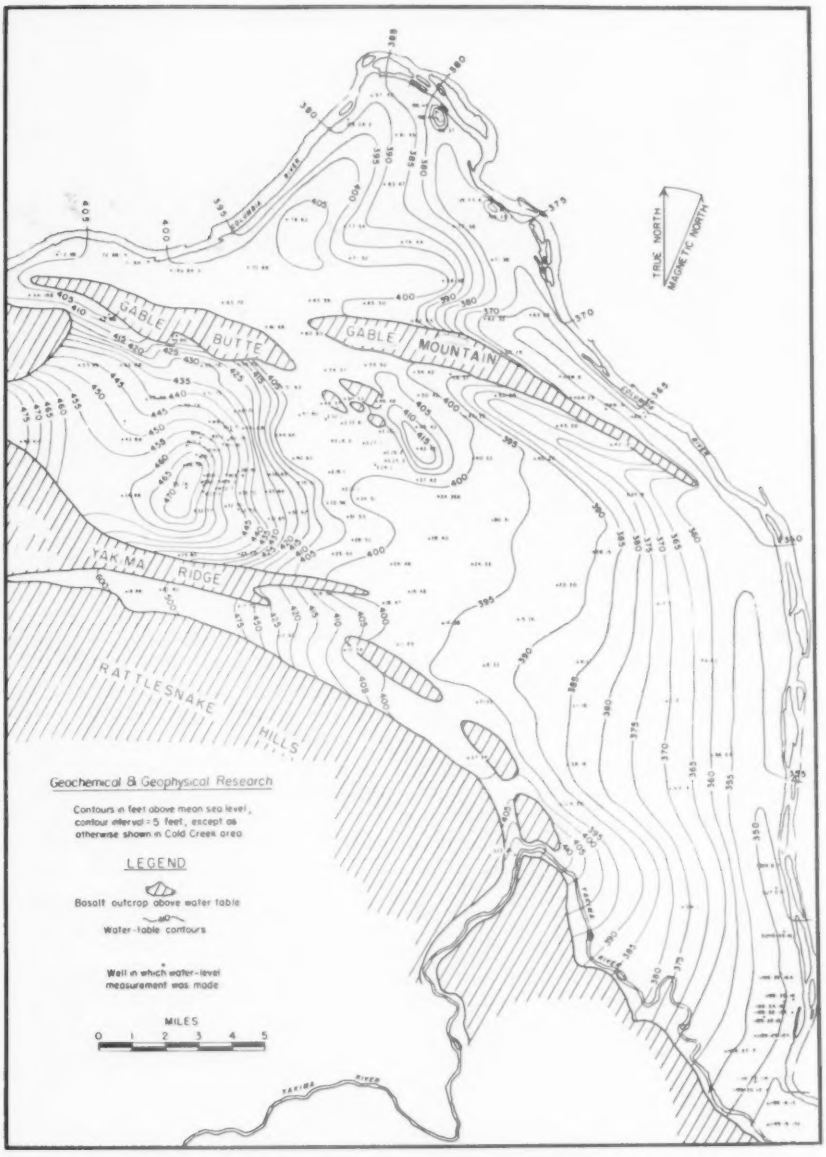
GABLE BUTTE
GABLE MOUNTAIN
YAKIMA RIDGE
RATTLESNAKE HILLS
TRUE NORTH
MAGNETIC NORTH
Geochemical & Geophysical Research
Contours in feet above mean sea level, contour interval = 5 feet, except as otherwise shown in Cold Creek area
LEGEND
Basalt outcrop above water table
Water-table contours
Well in which water-level measurement was made
MILES
0 1 2 3 4 5
YAKIMA RIVER

FIGURE 7.—Ground-water contours, Hanford Works area, June 1960.

water does not penetrate the basalt, it must eventually leave the basaltic basin via either the Columbia or Yakima Rivers. Assurance is thus provided that any radioactive materials which reach the ground water will not travel great distances through unknown channels to areas which might be overlooked in the monitoring program.

The most recent consolidation of data

on ground water elevation is shown on the contour map of Figure 7. Except for the mounds created by the utility water and low-level wastes of the separations plants, the water table slopes toward the Columbia River at a gradient of about 5 to 10 ft/mile. This information, in combination with extensive measurements of aquifer transmissibility and tracer tests to determine flow paths, has lead to an estimated average travel time from the disposal sites to the Columbia River of at least decades. Inasmuch as the only nuclides which are permitted to enter the ground water in significant amounts have half-lives of less than three years, appreciable decay before reaching the river is thus assured. Furthermore, these nuclides must travel through the ground-water sediments a distance of some 10 miles before reaching the river; this provides additional opportunities for ion exchange. To date there has been no clear evidence that any of the radioactive materials placed in the ground at the separations plants have reached either the Columbia or Yakima Rivers.

Columbia River

Tracking of the reactor effluent released to the Columbia River is, of course, technically much simpler than following the ground water, because the channel and flow rate of the river are well known. Certain features peculiar to the effluent must be determined, however, and these include the dispersion pattern, the degree of retention of particular radionuclides in the river sediments and biota, and the average transport times between the outfalls and the points of use. Because the nuclides carried by the river water are available to aquatic forms and to irrigated crops, the possibility of exposures arising from a variety of foodstuffs must also be investigated.

To determine the distribution of the effluent as it is swept downstream, surveys have been made under various hydrographic conditions. The radioactive materials discharged with the effluent can be detected in extremely small concentrations; therefore, they serve as effective tracers for such work. Although the effluent is released at the bottom of the river, it immediately becomes distributed between the bottom and the surface, a depth of from 20 to 40 ft. Distribution across the river, a distance of 1,000 to 2,000 ft, is accomplished largely by turbulent diffusion and proceeds much more slowly. Even after traveling 20 to 30 miles downstream to the vicinity of Richland (see Figure 1), the effluent is not quite uniformly mixed throughout the river. Just below Richland, the Columbia is joined by the Yakima River, which tends to lower the concentration of effluent along the west shore. About 10 miles farther downstream, just below the city of Pasco, the Snake River enters from the east and tends to lower the concentration of effluent along the east shore for several miles. At McNary Dam, some 30 miles below the mouth of the Snake River, the concentration is essentially uniform.

Not all of the radionuclides released to the river remain in solution. Inventories made at Pasco, some 35 miles downstream from the reactors, indicate that an average of only about 40 per cent of the expected quantity of radioactive material is present (after correction for radioactive decay). The balance of the material is removed by suspended silt particles, bottom sediments, and living organisms. Because each element behaves in a different manner, the amount of depletion differs for each radionuclide and varies from less than 10 to more than 60 per cent (8). Of the abundant nuclides in the reactor effluent, only Cr^{51} and Zn^{65} are sufficiently long-lived (27- and 245-day half-lives, respectively) to show measurable accumulation in the bottom sediments. At the existing rate of addition of these nuclides to the river, there will be no further buildup, because an

equilibrium has been reached between addition and loss by radioactive decay.

Biological Chains

Some of the radionuclides contained in the reactor effluent are assimilated by living organisms either directly or through a series of transfers in the food webs, and may appear in fish, wildlife, and farm products (9). These biological pathways, some of which may be highly complex, can be as important as the physical routes in carrying certain radioactive materials to man. In specific cases, radionuclides which have been dispersed in a diluting medium may be reconcentrated. The mechanisms involved in this bioaccumulation of radionuclides and the need for identifying the significant routes involved have been described previously (10) (11).

The possibility of radionuclides from the effluents appearing in biological forms was recognized at the time the Hanford plants were built and a substantial research and monitoring effort has been devoted to this general area. Two distinct biological pathways have emerged which are of interest as possible sources of effluent nuclides to man. One is the concentration of P^{32} and Zn^{65} by algae, with subsequent transfer of these nuclides through food webs to fish, shellfish, and waterfowl harvested outside the boundaries of the Hanford project. The other is the accumulation of Zn^{65} on pasture grass irrigated with Columbia River water and subsequent transfer to grazing animals and milk.

Air-Borne Waste

Although atmospheric studies are not a prime consideration of this paper, they are an important part of the waste control program at Hanford. The need for information on the dilution, dispersion, and eventual deposition of air-borne contaminants released through plant stacks is quite comparable with that for the liquid wastes and has entailed both synoptic and experimental meteorological studies at Hanford since the site was selected. This work, which has been described by Hilst (12), has included: (*a*) the development of information needed to predict the concentrations of radioactive materials which will be experienced at ground level within 1½ miles of the stacks under a variety of atmospheric conditions and (*b*) studies of the long-term average concentrations encountered at various distances and directions from Hanford. Much of the work has involved the experimental release of non-radioactive tracers into the atmosphere; the results have led to improved methods of predicting atmospheric diffusion during periods of stable temperature stratification. There has evolved from this work "a system for stack emission control whereby the maximum permissible emission rate is specified on the basis of maximum permissible short-term concentrations, the existing meteorological conditions, and the flow rate in the stack" (12).

The most biologically important radionuclide normally present in the stack gases is I^{131}, which eventually settles on vegetation and can subsequently be deposited in the thyroid glands of grazing animals. Small quantities may also reach man via garden produce and milk. A substantial research effort at Hanford has been devoted to clarification of the mechanisms involved in the uptake and deposition of I^{131} in domestic animals and local wildlife and to determination of the maximum permissible daily intake for this nuclide in sheep.

Measuring Radiation from Environmental Sources

The success of a radioactive waste management program developed for an industrial complex such as the Hanford operations must be judged on the basis of the total radiation dose received by

persons living in the vicinity of the plant and by the biota of economic or aesthetic importance. Control of the wastes must, therefore, be responsive not only to circumstances prevailing at the point and time of release but also to conditions which will exist at the points of exposure.

The exposure received by an individual may accrue from radioactive materials originating from more than one point of release or, at least, from radionuclides which have taken divergent pathways through the environment. For example, minor exposures in the vicinity of the Hanford operation might result from: (*a*) swimming in the Columbia River, (*b*) drinking river water, (*c*) eating fish caught from the river, (*d*) drinking milk from cows which have grazed on irrigated pastures, and (*e*) eating locally grown leafy vegetables. A number of additional potential sources of exposure can also be postulated (13). Radionuclides from the reactors would be identified with sources (*a*), (*b*), (*c*), and (*d*), although the relative importance of specific nuclides would differ in each case. Atmospheric contaminants from the separations plants and from world-wide fallout would contribute in cases (*d*) and (*e*).

To evaluate the significance of exposures which might conceivably result from the various sources, an extensive environmental monitoring program has been established. Included on routine schedules are direct measurements of the radiation emanating from the ground, from the river, and from the atmosphere, and radiochemical assay of the concentrations of specific nuclides in the effluent from each reactor, in the Columbia River water and sediments, in drinking water supplies, in farm crops and products, in fish and waterfowl, in stack gases, in the atmosphere, in native grasses, and in rabbits. Sampling frequency varies with the kind of material and distance from the plant. River water, for example, is sampled continuously at one location and on a weekly basis at several other sites in the immediate vicinity of the plant, but only twice monthly at a point some 250 miles downriver. Sampling of foodstuffs is dependent on their seasonal availability. In addition to the routine monitoring program, special surveys are carried out from time to time to obtain supplementary data and to define uptake and transfer mechanisms.

During 1959, some 30,000 samples were collected as a part of the environmental monitoring program. These were processed to provide about 55,000 analytical results. Included in this total are approximately 12,000 samples of water from the Columbia River, from the municipal supplies of Pasco and Kennewick, and from wells and other domestic sources. The radioisotopic content of the water in the municipal water system of Pasco was recently described by Junkins (14).

Where a complex mixture of radionuclides is present, precise exposure evaluation cannot be accomplished solely from the gross determinations of the radioactivity of the mixture. It is necessary to determine the concentration of each individual radionuclide which is apt to be of significance. Of the total number of nuclides detected in the effluent, 17 are of sufficient interest that their concentration in water from the Columbia River or the municipal supplies is measured on a routine basis. Analyses of less than a dozen are actually required for routine exposure evaluation. For the particular mixture of radionuclides present, the maximum permissible concentrations allowable in the gastrointestinal tract form the reference base* to which observed concentrations in the water may be compared.

During 1959 the combined concen-

* For residents of the Pasco-Kennewick area, one-tenth of the MPC's listed in the National Bureau of Standards' Handbook 69 for continuous occupational exposure are used.

trations of the radioactive materials present in the Pasco municipal system amounted to about 5 per cent of the maximum permissible amount. The value for Kennewick was less. Other sources, such as swimming in the river and consumption of local foods, would add to the total exposure received by some individuals. Although wide variations in dietary habits and outside activities preclude a precise statement of the combined exposure from all environmental sources, estimates for typical individuals fall in the range of 10 to 15 per cent of the maximum permissible exposure recommended by the National Committee on Radiation Protection and Measurement (2). For those individuals who consume unusually large amounts of local fish that have accumulated radiophosphorus, estimates indicate that the composite exposure may reach as much as 40 to 60 per cent of the appropriate limits (15).

A new facility has recently been added at Hanford which permits direct estimate of the radionuclides present in individuals by measurement of the radiation emanating from them. Measurements are made with a large and highly sensitive scintillation-type counter contained in a small room which is heavily shielded to minimize background radiation from cosmic rays and other extraneous sources. This station provides data on plant workers, local residents, and on visitors from distant sections of the country. Apart from naturally occurring radionuclides and those attributable to world-wide fallout, radiozinc (Zn^{65}) is the most commonly detected nuclide present in local residents (16). Results to date suggest that the body burden of Zn^{65} in most individuals is much less than one per cent of the applicable limit, but in rare cases may approach two per cent. These direct measurements support the conclusion that radioactive wastes released from the plants are not causing undue exposure in the environs.

Determining Permissible Concentrations

The maximum permissible exposure considered appropriate for persons whose occupation involves the use of radiation sources and for persons living outside of the controlled sites has received close attention by such scientific bodies as the International Commission on Radiological Protection, the National Committee on Radiation Protection and Measurements, the National Academy of Sciences-National Research Council, and, recently, the Federal Radiation Council. The published reports of these bodies include recommendations for a variety of circumstances and radiation sources and these recommendations are updated from time to time as new knowledge becomes available. The research program at Hanford has recognized the need for providing additional information on the environmental, metabolic, and toxicological parameters associated with those radionuclides which occur in significant concentrations in plant effluents. This work has included studies concerned not only with a refinement of values applicable to the human case, but also with safe concentrations of effluent in the environment for the protection of crops, domestic animals, fish, and wildlife (17).

One area of extensive research has been the determination of a maximum permissible concentration of I^{131} in air based on the accumulation of this nuclide in the thyroid glands of sheep which graze on local vegetation (18) (19). The limit on the release of I^{131} from plant stacks derived on this basis is about 3,000-fold more restrictive than would be applicable for air breathed by man.

Bio-assay tests on the reactor effluent have been carried out on fish at Hanford since the first year of operation (20). This work has demonstrated that the concentration of effluent in the Columbia is well below the toxic level. Although long-term laboratory

tests using effluent concentrations substantially higher than those encountered in the river have produced toxic effects in young fish, studies on the separate effects of heat and process chemicals have shown that the limiting factor is not the radionuclides, but dichromate added to inhibit corrosion in the reactors (21) (22). The chronic studies with hexavalent chromium using sensitive life stages of fish has led to a locally recommended limit of 0.02 mg/l Cr(VI) for the Columbia River, a limit appreciably below that permitted for humans and one which is perhaps more than 100 times more stringent than would have been arrived at by short-exposure bio-assay techniques.

The potential effect of reactor effluent on irrigated crops has also been studied at Hanford through the use of experimental plots. There appears to be essentially no problem in this area, as no significant effects have been observed in plants grown in soil which contained the equivalent of 25 years' accumulation of effluent constituents (23).

Conclusions

With the startup of the Hanford plutonium production plant in 1944, large volumes of radioactive waste were created which required unprecedented precautions in handling, storage, and release to the environment. Because of the potential for hazardous exposure and the lack of prior experience, all phases of the waste handling program were approached with great caution and unusually large margins of safety. During the few years which have elapsed since the first chain reaction was produced, the technology associated with handling of radioactive materials has grown from infancy to a state of proven ability. This rapid growth has been accomplished not only through operating experience but also in large part through aggressive programs of research and development.

The Hanford plant, with its great variety and quantities of radioactive wastes, can be considered as a proving ground for disposal practices. In fulfilling this function, many of the research and development programs have been integrated with, or have become a part of, the normal waste control operation. For this reason, it is difficult to break down the costs which might ordinarily be allocated to this function. Some approximations are possible, however. As recently stated by Parker (15), "The capital costs of all Hanford facilities or systems involved in the collection, handling, processing, monitoring, and control of gaseous, liquid, and solid waste effluents are approximately $114 million. The related annual operating and maintenance costs are about $2 million, while research and development activities concerned with waste disposal problems are conducted at a level of $1 million annually."

The substantial investments in facilities, methodology, and surveillance at Hanford open the way for equally safe but less expensive waste programs at future atomic energy plants and has demonstrated the feasibility of selecting sites closer to population centers. Hanford experience has shown that, with rational operation, reactor effluent can be discharged into a large river without degrading its use for other purposes downstream. Radiation exposures in the environs of most water-cooled power reactors of contemporary design will be even less, because the primary coolant is recirculated rather than released to the environment.

Satisfactory retention of air-borne contaminants requires extensive scrubbing and filtration but seemingly presents no problems that cannot be overcome by the installation of sufficient equipment of modern design. Ground contamination in the vicinity of Hanford attributable to plant operation is

currently less than that which has resulted from world-wide fallout.

Tank storage, such as practiced at Hanford and other large installations, is not generally considered as an ultimate solution to the high-level waste problem. Nevertheless, the success of this practice to date, especially in combination with ground disposal of intermediate-level waste, provides assurance that development of power from fissionable materials can progress in an orderly manner for several decades without restriction because of accumulated liquid wastes. This should be ample time for the perfection of methods which are superior to the storage of the waste as liquids in tanks. The practicability of tank-storage of high-level wastes from power production for some time to come has been pointed out by Parker (13), who states: "Probably it will be between 20 and 25 years before the national storage demand from nuclear power equals the present demand at Hanford. This is greater than the length of time during which a significant radioactive waste disposal problem has existed."

Waste disposal practices at Hanford have logically used to advantage the topographical and climatological features of the area. Through careful study of the hydrology, geology, meteorology, and biology of the site and the movement of radioactive materials through and between the various media, it has been possible to release wastes to the Columbia River, to the atmosphere, and to the ground with safety. The propriety of such releases has been confirmed by extensive radiation monitoring in the environs of the plant.

Because an individual may receive exposure from radioactive materials that have originated at several different sites and have followed diverse pathways, the basis of waste control has properly been placed at the point of exposure. The contributions from all plant facilities are thus combined in the exposure evaluation. Nevertheless, the goals of the over-all program must, in the end, be attained through operational control of the release of wastes at each individual process facility.

Acknowledgment

Because of the broad nature of this paper, contributions, including some of the illustrations, have been received from the several research and operating groups at Hanford which have responsibility for various phases of the over-all waste control program. The generous assistance of the authors' many colleagues is gratefully acknowledged.

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YOU WILL BENEFIT BY THE MESSAGE ON PAGE 444 OF THE APRIL ISSUE

OPERATION OF SEWAGE TREATMENT PLANTS

Since the September 1960 issue of the Federation Journal, this section has contained one or more chapters of Federation Manual of Practice No. 11, "Operation of Sewage Treatment Plants." With the introduction of these chapters on page 1000 of the September issue, you were invited to submit comments which might be used by the subcommittee in preparation for final publication as a Manual of Practice.

Many have accepted this invitation and comments received in the Federation office have been noted and are being held for the use of the subcommittee. If you have submitted such comments and they have not been acknowledged, please accept this as acknowledgment and our expression of appreciation for your time and trouble in making them. If you have comments but have not submitted them, please do so as soon as you can.

As present plans are to conclude publication of the Manual in the June issue, we urge that you send your final comments as soon as possible after receiving it. In this way, comments made from those in North America should reach the Federation office by July 15 and comments from most readers outside North America should reach the Federation office by August 15. All comments received by August 15 will be considered by the subcommittee.

19. RECORDS AND REPORTS

Regular records and reports of operation of sewage treatment plants serve many useful purposes. They are helpful to those directly responsible for plant operations and to municipal officials, consulting engineers, state regulatory agencies, and others who have similar facilities and related problems.

The operator should use these records as a guide in regulating, adjusting, and modifying the plant facilities and operation. They serve as a check on his visual observations, his sense of smell, and his judgment, sometimes confirming, sometimes denying, but more often refining the accuracy and

This is Chapter 19 of Operation of Sewage Treatment Plants, *Manual of Practice 11. Serialization of this manual began in the September 1960 issue.*

dependability of his conclusions. Of great importance also is the establishment of a reliable continuing record of proof of performance, justifying decisions, expenditures, and recommendations.

Such records often are the only sound basis upon which administrative officials may negotiate with an existing or potential customer, plan corrective measures for deficiencies on the sewer system or plant, or justify budgetary changes for expanding needs. Records provide much useful and valuable information for release to the customers served by the system and other groups and individuals in the community. Should a law suit be threatened, records and reports together with the operator's testimony provide the administration and legal counsel with factual information upon which a sound defense and adjustment may be established.

Operation reports should be furnished regularly to the state regulatory agency responsible for control of pollution and protection of health. A report sufficiently complete for the operator's needs and those of the local administrative official allows the technical staff of the state agency to determine the extent to which the objectives of sewage treatment have been met.

19.1 TYPES OF RECORDS

Records which should be maintained at a sewage treatment plant may be separated into two main classifications: (*a*) records of a descriptive, planning, or inventory type related to the physical plant, and (*b*) records of performance.

19.11 Physical Plant

Records of this type which should be available for reference at the plant include the following:

1. Report of designing engineers, including basis of design, capacities of all plant units, population served, service area, and other usual information.
2. Contract plans and specifications on entire plant.
3. "As built" plans and specifications.
4. Shop drawings and operating instructions for all equipment.
5. Costs of each major unit, equipment item, and landscaping.
6. Detail plans of all piping and electrical wiring.
7. Hydraulic profile showing operating water elevations in all major plant units.
8. Complete record on each piece of equipment including name of manufacturer, identifying number, rated capacity, and dates of purchase and installation. A card record kept up to date as to condition, items repaired, and cost thereof is useful in determining when the equipment may need repair or replacement.
9. For each industry discharging wastes, a card record should be kept showing type of waste, volume, time and periods of discharge, chemical and physical characteristics of the waste, and control methods of the industry.

19.12 Records of Operation

At each plant data on operation to be collected, analyzed, and reported should be geared to the particular and peculiar needs and circumstances governing operation. Never should records be made for the sake of records. The operator should justify each meas-

FIGURE 19–1.—Report form for flow data and other miscellaneous information.

OPERATION REPORT of SEWAGE TREATMENT PLANT FOR . . .

MONTH.....19..... MISCELLANEOUS DATA OPERATOR.....

Date	Weather				Raw Sewage			Grit (cu ft/ mil gal)	Plant Effluent, Coliform Density (MPN/100 ml)	Chlorine (lb)	Power (kw-hr)	Aux. Fuel†	Remarks
	Precip (in.)	Temp. (°F) (max)	Temp. (°F) (min)	Type*	Temp (°F)	Flow (mgd)	pH						
1													
through													
31													
Mean													

* C—Clear; W—Windy; CL—Cloudy; CA—Calm; R—Rain; S—Snow. † Indicate kind and unit of volume.

FIGURE 19–2.—Report form for primary treatment data.

OPERATION REPORT of SEWAGE TREATMENT PLANT FOR . . .

MONTH.....19..... PRIMARY TREATMENT DATA OPERATOR.....

Date	5-Day BOD					Suspended Solids					Suspended Volatile Solids				Remarks
	Influent		Effluent		Removal (%)	Influent		Effluent		Removal (%)	Influent		Effluent		
	(mg/l)	(lb)	(mg/l)	(lb)		(mg/l)	(lb)	(mg/l)	(lb)		(mg/l)	(lb)	(mg/l)	(lb)	
1															
through															
31															
Mean															

FIGURE 19-3.—Report form for trickling filter data.

OPERATION REPORT of SEWAGE TREATMENT PLANT FOR . . .

VOLUME (cu ft)..... RECIRCULATION PATTERN.....

MONTH.....19..... TRICKLING FILTER DATA OPERATOR.....

Date	R*	5-Day BOD					Suspended Solids					Suspended Volatile Solids		Removal		Remarks
		Primary Effluent (lb/day/1,000 cu ft)	Final Tank Effluent		Removal		Primary Effluent (lb/day/1,000 cu ft)	Final Tank Effluent		Removal		Final Tank Effluent		Total Plant		
			(mg/l)	(lb)	(%)	(lb/day/1,000 cu ft)		(mg/l)	(lb)	(%)	(lb/day/1,000 cu ft)	(mg/l)	(lb)	BOD (%)	Suspended Solids (%)	
1																
through																
31																
Mean																

$$*R = \frac{\text{Filter Influent}}{\text{Plant Influent}}.$$

FIGURE 19-4.—Report form for activated sludge data.

OPERATION REPORT of SEWAGE TREATMENT PLANT FOR . . .

MONTH.....19..... ACTIVATED SLUDGE DATA OPERATOR.....

Date	Air Applied			5-Day BOD			Suspended Solids		Suspended Volatile Solids		Removal		DO Final Effluent (mg/l)	Mixed Liquor				Return Sludge		Waste Sludge (1,000 gal)	Remarks
	(hr)	(cfm)	(cu ft/lb BOD Rem.)	Primary Effluent (lb/day/1,000 cu ft)	Final Effluent		Final Effluent		Final Effluent		Total Plant			Suspended Solids (%)	Settleable Solids, 30 min (%)	Sludge Density Index	DO (mg/l)	(%)	SS (mg/l)		
					(mg/l)	(lb)	(mg/l)	(lb)	(mg/l)	(lb)	BOD (%)	SS (%)									
1																					
through																					
31																					
Mean																					

FIGURE 19–5.—Report form for intermittent sand filter data.

OPERATION REPORT of SEWAGE TREATMENT PLANT FOR . . .

MONTH.....19..... INTERMITTENT SAND FILTER DATA OPERATOR.....

Date	Dose (gpd/sq ft)	5-Day BOD						Suspended Solids						DO Final Effluent (mg/l)	Remarks
		Influent		Effluent		Removal		Influent		Effluent		Removal			
		(mg/l)	(lb)	(mg/l)	(lb)	Sand Filter (%)	Total Plant (%)	(mg/l)	(lb)	(mg/l)	(lb)	Sand Filter (%)	Total Plant (%)		
1															
through															
31															
Mean															

FIGURE 19–6.—Report form for digester and sludge data.

OPERATION REPORT of SEWAGE TREATMENT PLANT FOR . . .

MONTH.....19..... DIGESTER AND SLUDGE DATA OPERATOR.....

Date	Raw Sludge					Supernatant						Sludge near Bottom				Temp. (°F)	Gas		Remarks (include gal of sludge to beds)
	(gal)	Loading (lb/1,000 cu ft)	pH	Total Solids (%)	Volatile Solids (%)	(gal)	pH	Total Solids (%)	Volatile Solids (%)	Suspended Solids (mg/l)	5-Day BOD (mg/l)	Total Solids (%)	Volatile Solids (%)	Volatile Acids (mg/l)	pH		Produced (cu ft)	Wasted (cu ft)	
1																			
through																			
31																			
Mean																			

FIGURE 19-7.—Report form for vacuum filter and incineration data.

OPERATION REPORT of SEWAGE TREATMENT PLANT FOR . . .

MONTH ..... 19..... VACUUM FILTER AND INCINERATION DATA OPERATOR .....

Date	Sludge to Filter			Chemicals to Filter			Filter	Filtrate					Filter Cake			Incineration			Remarks
	(gal)	Total Solids (%)	Dry Solids (lb)	pH	CaO (lb)	FeCl$_3$ (lb)	(%)	Operation (hr)	Yield (psf/hr)	(gal)	pH	Susp. Solids (mg/l)	Vol. Susp. Solids (% of TS)	BOD (mg/l)	(1,000 lb, wet)	Total Solids (%)	Volatile Solids (% of TS)	Operation (hr)	Yield	Fuel Btu	
1																					
through																					
31																					
Totals																					
Mean																					

urement, observation, calculation, and report on the basis of expected usefulness and value. At most plants limitations of personnel, money, and facilities restrict the amount of record-keeping that can be done before a part of the operating program is sacrificed.

19.121 Daily Records:—Daily records usually are recorded in three forms. One, in the form of a continuing diary, may contain a wide variety of factual information on matters such as progress of construction or maintenance work, failure of a piece of equipment, accidents to personnel, floods or unusual storms, bypassing of a plant unit, complaints registered, and visitors. This information obviously is valuable for later reference.

Routine reports on personnel, payroll, small purchases, and related information are usually required only in the larger plants.

Daily bench sheets used in the calculations for laboratory determinations, measurement charts on flow, gas production, and consumption, power used, weather, temperature, rainfall, and other hydrological data, sewage temperatures, and other physical information are examples of the sources and types of data which should be assembled at medium-sized and large plants on a daily basis. These data are entered each day on the monthly operation reports.

19.122 Monthly Operation Reports:—The monthly operation report should contain all of the significant physical measurements and laboratory results on plant performance. The report form should be neat and on good quality paper, preferably with printed headings and lines. It should be standard size, 8½ by 11 in. sheets for convenient handling and filing. Samples illustrating format, arrangement of information, and basic types of data are shown in Figures 19–1 to 19–7.

Laboratory determinations required for process control are discussed in the preceding chapters.

19.2 RELATING PHYSICAL MEASUREMENTS AND LABORATORY RESULTS TO OPERATION

19.21 Value of Results

The results of the various measurements and determinations should reflect the operating condition of a plant. They should indicate specifically the load delivered to the plant, including the total organic load, its characteristics and treatability, and the rates at which the wastes arrive at the plant. These results should tell the operator what the plant as a whole and each part of it has accomplished in treating the waste and furnish him with needed information about the effect of the plant effluent on the receiving watercourse.

Varying results are often an indicator of impending difficulties in plant operation. Uniformly increasing loads indicate the rate at which sewage loads are approaching plant capacity. Sudden variations in results may indicate such things as accidental discharges or damage to the sewer system.

19.22 Normal Range of Results

Interpretation of measurements and analytical results requires first the establishment and recognition of the normal range of values for the various items under consideration.

19.221 Domestic Sewage:—Sewage of primarily domestic origin contains organic material in amounts closely proportional to the size of the contributing population. In the U. S. the per capita contribution of BOD is about 0.17 lb/day, and for suspended solids, close to 0.22 lb/day. But such things as industrial wastes, ground garbage, and living habits of people change these values. A large and sudden increase or decrease in population such as occurs in a small college town at the beginning or end of a school term results in a significant variation from normal loads. While the total weight of organic material which will be contributed by a given number of persons can be closely predicted, the concentration of these materials in the liquid-carried waste will depend on such factors as the type of sewer system (whether separate sanitary or combined storm-sanitary), living habits and economic status of the contributing population, and the water consumption, which often is greatly modified by the industrial complex of a community.

19.222 Industrial Wastes:—Liquid wastes originating in industries may contain domestic sewage and other organic or inorganic wastes, either separately or in combination. A separate determination of normal values would have to be made for each industry, including a study of the operations carried on and the waste control measures in effect.

19.23 Departures from Normal Values

Significant departures from normal ranges for any particular waste or treatment works should be investigated to determine the cause and permit either correction of the responsible factors or adjustment of the treatment facilities. It is important to determine whether these departures are irregular, cyclic, or permanent. The following is a short discussion of several variations in measurements and analytical results which might be experienced in a sewage collection system and treatment works.

19.231 Sewage Solids:—A decrease in the solids content of raw sewage as measured by the suspended solids test might be caused by sedimentation in the sewer system. This sedimentation might be caused by sewers laid on grades insufficient to maintain self-cleansing velocities or by partial blockages in the sewers which also would reduce velocities.

Variations in the concentration of sewage solids might be caused also by

scouring of previously settled solids or variations in the quantity of water acting as a liquid carrier for the solids. For example, material might settle in a combined sewer under the prevailing velocities in dry weather, thus reducing the solids content of sewage delivered to the treatment works during that period. Increasing quantities of flow during storm runoff would result in higher velocities which then might resuspend the previously settled solids, increasing the solids content of the sewage arriving at the treatment works. Other possible causes for solids variations to be investigated are the seasonal operation of certain types of industrial activity such as food packing and tanning.

A decrease in the removal of suspended solids by a settling tank as measured by the suspended solids test of influent and effluent, could result from a change in the amount or character of the waste being treated. Sewage with a high concentration of solids normally permits a higher percentage reduction in solids by sedimentation than dilute sewage, so a change in solids concentration of the waste to be treated might well be reflected in a change of treatment efficiency.

Unless settled solids are removed thoroughly and frequently from the bottom of a settling tank, septic conditions may be established. This digestion within the tank might produce sufficient gas to float some of the solid particles to the surface where they would be discharged with the tank effluent, thus reducing the efficiency of the unit.

19.232 Biochemical Oxygen Demand: —The oxygen demand of sewage as measured by the standard 5-day BOD test is one of the best indicators of the character of sewage. An extreme increase in BOD concentration could be caused by septicity occurring in the sewers or treatment plant, or by the discharge of organic industrial wastes such as sugar, and food or meat packing wastes.

It is important to recognize the relationship between the concentration of BOD and suspended solids in any sewage. If a high BOD is the result of dissolved organic material such as sugars, it cannot be removed with the suspended solids as they settled out in the sedimentation units. This type of waste would require secondary treatment for stabilization of the oxygen demand. Thus a study of the BOD–suspended solids results, both in the raw sewage and the effluent from the treatment units, becomes important to an interpretation of analytical results. Such information is of further value when determining the type and amount of treatment required for a specific sewage. BOD which is removed with the settling suspended solids will exert a greater demand on the stream's oxygen resources in those areas traversed by the solids and in which the solids settle; conversely, BOD associated with dissolved solids may well exert its oxygen demand over a much greater portion of the stream since the demand would remain longer in the stream flow and would not be localized by sedimentation.

An abrupt drop in the normal BOD of a sewage might be traced in some cases to a discharge of toxic materials such as metal plating wastes which would so inhibit biological activity in the test procedure as to give a false, low BOD result.

19.233 pH:—Departures from a normal of most concern in a sewage treatment works are those where the pH is lowered or remains in the acid range. Septic sewage, for example, or sludge in early stages of digestion will have a pH below 7.0. It should be noted that a low pH is an indication of such acid conditions rather than the cause. Reference to an act to "correct or adjust pH" is actually a reference to correction of a condition which has resulted in the pH variation. Correction of an acid condition in sludge or sewage usually is best accomplished by elimination of the cause rather than by

chemical adjustment. For example, excessive amounts of acid industrial wastes are usually more effectively dealt with at the source than at the treatment works. In addition, correction of such discharges at the source protects the sewerage structures.

19.234 Temperature:—A sudden drop in sewage temperature should prompt the operator to investigate such possible causes as infiltration of ground or surface water. Such a drop might follow a rise in air temperature causing a major thaw of ice and snow. A significant change in sewage temperature would be accompanied by a change of viscosity of the sewage, hence the settling characteristics could be expected to show some variation.

19.235 Sewage Volumes–Rates of Flow:—Abrupt increases in total volumes of sewage should be studied in the light of any corresponding changes in the composition of the waste. For instance, an increase in volume caused by a break in a siphon under a river, freely admitting river water to the sewer system, would be accompanied by a decrease in sewage strength as measured by the BOD and solids tests. Spasmodic increases in rates of flow accompanied by a temperature rise and possibly soap or detergents could be the result of discharges from laundries or cooling waters from a factory or power plant.

Decreases in flow rates should lead to an investigation of such possible causes as sewer stoppages, failure of overflow regulators on combined sewer systems, pipe rupture, or pump failure.

19.236 Low Gas Production:—The rate of digester gas production will vary from plant to plant depending upon such variables as digester temperature, mixing efficiency, presence of toxic materials, excess acidity, and character of the digesting sludge. An abrupt drop in the normal rate of gas production might be caused by excessive amounts of toxic materials such as metal plating wastes, or certain pharmaceuticals.

Then too, a measured drop in gas production might not be due to a drop in biological activity, but merely the result of an inefficient meter or a gas leak ahead of the meter. A gas leak could falsely indicate less gas produced, although the destruction of volatiles might not be changed. Overloading a digester, inefficient mixing of raw and digesting sludge, and failure to maintain proper digestion temperatures are other possible causes to be investigated when a drop in gas production is noticed.

A drop in the pH of digesting sludge might be attributed to a decrease in digestion activity due to lower temperatures, excessive acid, excessive scum, an overload of raw sludge, or the admission of acids or other toxic materials into the units.

19.237 Chlorine Requirements and Residuals:—An increase in chlorine requirements of a plant effluent often accompanies an increase in organic content resulting from decreased treatment efficiency. Septicity of raw sewage or primary plant effluent also causes increased chlorine demands. Certain industrial wastes such as cyanides have a strong chemical demand for chlorine. The cause of significant increases in chlorine requirements should be sought out and corrected, particularly in cases where high-order bacteriological control is important. In addition to making such control more difficult, the increase in chlorine dosage is costly.

19.238 Effect on Receiving Stream:—It is important to view departures from the norm as to their possible effect upon the receiving watercourse. For instance, decreased efficiency of sedimentation and an increase in organic material in the plant effluent usually are not as critical for a stream in winter as they are in the hot dry months when the stream flow is lower and its oxygen content is reduced.

20. SAFETY

Employee hazards in sewage plants include exposure to:

1. Physical injuries,
2. Body infections,
3. Oxygen deficiency,
4. Noxious gases or vapors, and in some cases,
5. Ionizing radiations.

These occupational hazards are largely avoided by the execution of safe practices and the use of safety equipment. The dangers are many; this is supported by the man-hour accident records of insurance companies.

It is the responsibility of sewage plant supervisors to acquaint themselves with the hazards associated with plant maintenance and operation, and to take steps to eliminate them. Accidents do not happen—they are caused! By thinking "safety," it soon becomes a state of mind.

20.1 PREVENTION OF PHYSICAL INJURIES

20.11 Lift Objects Safely

Teach employees to lift objects with the aid of the leg muscles instead of the back. This will reduce ruptures and back injuries. Use hoists or power trucks to lift heavy objects and avoid hurrying. See that adequate help under proper supervision is available. The handling of objects constitutes the major source of compensation injuries.

20.12 Prevent Falls

Be cautious when using vertical ladders or steep, narrow stairs. Install a hoop cage around vertical ladders more than 10 ft high. Employ good housekeeping. Keep tools and portable equipment in designated places. Maintain walks, stair treads, and ladder rungs free of grease, oil, or ice. Remove debris from working areas. Keep manhole covers in place or provide guards. Erect judiciously placed warning signs at danger spots. Install fencing or guard rails around settling tanks or at other locations where operators might fall. Falls are the second largest source of compensation injuries.

20.13 Avoid Body Injuries

Remove manhole covers preferably with a hook lifter rather than a pick. Unless the cover is very heavy, it is safer to have one man pull the cover free of the manhole shaft. Never leave a cover partially over a manhole shaft. Instruct employees to wear work gloves when handling large objects. Provide metal guards for all moving parts of machinery. Use ample natural or artificial lighting in work areas. The employment of light-colored paints for interior rooms is suggested.

20.14 Avoid Electrical Shocks or Injuries

Place rubber mats in front of switchboards. Open the main control switch and tag it when working on a motor or other electrical equipment. See that all electrical equipment is well grounded and all exposed wire taped.

20.15 Protect Plant Against Fire

Equip the plant with an adequate number of fire extinguishers. In addition to carbon dioxide extinguishers

This is Chapter 20 of Operation of Sewage Treatment Plants, *Manual of Practice No. 11. Serialization began in the September 1960 issue.*

for electrical fires, provide one or more of the soda ash and acid type. Stage fire and emergency first-aid drills at large plants.

20.16 General Preventive Measures

Instruct all operators to use a safety belt in manhole shafts, tanks, or other structures deeper than 8 to 10 ft. Two men should stand by to remove the operator, if necessary. See that all chief operators and foremen have first-aid training. Post prominently the phone numbers of several physicians, the nearest hospital, the nearest fire station, one or more ambulance services, and the police station.

20.2 PREVENTION OF BODY INFECTIONS

20.21 Nature of Body Infections

Sewage and its by-products are potential hazards to treatment plant employees. These potential hazards include the water-borne diseases such as typhoid fever, paratyphoid fever, dysentery; and infectious jaundice, and the danger from tetanus.

The following preventive measures are suggested:

20.211 Safe Drinking Water:—Provide safe water for drinking. Avoid all physical cross-connections between the drinking-water supply and piping or facilities containing sewage, sludge, or other filth. Cross-connections of even a temporary nature should not be allowed (and are usually prohibited by state or local regulations).

20.212 First Aid:—Provide a first-aid kit for immediate treatment of minor cuts and wounds. Except for injuries of a minor nature, wounds should be treated promptly by a doctor.

20.213 Safety Facilities:—Provide shower stalls, a dressing room for a change of clothing, and a lunch room at larger plants. Facilities for making coffee and a refrigerator for cold drinks and perishable foods are often more than refinements—they pay off in employee morale and health.

20.214 Immunizations:—Periodically provide typhoid and tetanus inoculations for all employees.

20.215 Personal Precautions:—Keep your hands below your collar while at work. Do not smoke when handling contaminated equipment. Wear rubber gloves when cleaning sludge pumps or performing other plant duties requiring intimate contact with sewage, sludge, screenings, and the like. Wash hands with hot water and soap before eating or smoking.

20.3 PREVENTION OF OXYGEN DEFICIENCY

Normal air contains about 21 per cent (by volume) oxygen and 79 per cent nitrogen. Any atmosphere containing less than 13 per cent oxygen is dangerous to human beings and is called an oxygen deficient atmosphere.

20.31 Causes of Oxygen Deficiency

Oxygen deficiency may occur in any confined space, such as a manhole or tank, by displacement of the air with some other gas, whether this gas is toxic or not. Oxygen deficiency may also result from the decomposition of organic matter such as is present in sludge. Absorption or chemical consumption of the available oxygen occurs in such cases. Basically, oxygen deficiency is the result of poor ventilation.

Oxygen deficiency in treatment plants occurs primarily in manholes, in any tightly covered pit or tank regardless of depth, in poorly ventilated rooms

or pits (especially basements) where digested sludge spillage has occurred, in partially emptied digesters, or in structures containing sludge gas piping or appurtenances that may be leaking.

20.32 Detecting Oxygen Deficiency

Use an oxygen-deficiency indicator equipped with an aspirator, sampling hose, and intake tube to measure oxygen level. Flame safety lamps, used by miners, should not be employed. The flame of an oxygen-deficiency indicator will usually be extinguished by an atmosphere containing less than 16 per cent of oxygen, and always by one below 13 per cent; it is, therefore, a safe indicator. If a combustible gas is also present, the flame height will increase and may dim, or the flame will flare up and then be extinguished. In such cases, check at once for combustible gases with a combustible-gas indicator. Oxygen deficiency indicators are described fully in the Federation's Manual of Practice No. 1, *Safety in Wastewater Works*.

20.33 Avoiding or Correcting an Oxygen-Deficient Atmosphere

Provide ample ventilation and remove source of diluent gases, if present. In rooms or structures, ventilation may be secured with:

1. Open windows or door louvres.
2. Fresh-air intakes near ceiling and mechanical exhaust ducts near the floor.
3. Fans.

In tanks, pits, and manholes, ventilation may be secured with:

1. Compressed air. The air pipe should extend to near the bottom of the structure.
2. A portable air blower. The discharge hose should extend well into the structure. The electric motor or gas engine furnished with the blower should be explosion-proof; otherwise the blower should be placed on the leeward side of the opening and at least 6 ft away. All other available openings in tanks and structures being ventilated should be uncovered to aid circulation.

The diluent gas which is most likely to contribute to oxygen deficiency in sewage plants is sludge gas. Carbon dioxide or nitrogen gas might serve as diluting agents in earth-bottom pits. Sludge gas accumulations must be avoided by preventing digested sludge spillage or gas leakage. Earth-bottom pits may be concreted.

20.4 PREVENTION OF NOXIOUS GASES OR VAPORS

A noxious gas or vapor is one directly or indirectly injurious or destructive to the health or life of human beings. It may present a hazard by causing burns, explosions, asphyxiation, or poisoning. Asphyxiation from gases may occur by chemical reaction, as in the case of carbon monoxide which combines with the hemoglobin of the blood causing oxygen starvation, or it may occur by mechanically excluding oxygen, causing oxygen deficiency.

Table 20–1 gives data on the common dangerous gases encountered in the sewage works field. Operators of sewage plants should be thoroughly familiar with the characteristics, sources, and means of testing for the gases in this table.

20.41 Explosion of Flammable Gases

Four conditions must exist before a gas explosion can take place:

1. Presence of a flammable gas,
2. Presence of air (oxygen),

TABLE 20–1.—Characteristics of Common Gases Encountered in Sewers, Wastewater Pumping Stations, and Treatment Plants

Gas	Chemical Formula	Common Properties*	Specific Gravity or Vapor Density (Air = 1)	Physiological Effect*	Max Safe 60-Min Exposure (% by Vol. in Air)	Max Safe 8-Hr Exposure (% by Vol. in Air)	Explosive Range (% by Vol. in Air)		Likely Location of Highest Conc.	Most Common Sources	Simplest and Cheapest Safe Method of Testing
							Lower Limit	Upper Limit			
Carbon dioxide	CO_2	Asphyxiant. Colorless, odorless. When breathed in large quantities may cause acid taste. Nonflammable. Not generally present in dangerous amounts unless an oxygen deficiency exists.	1.53	Cannot be endured at 10% more than few min, even if subject is at rest and oxygen content normal. Acts on respiratory nerves.	4.0 to 6.0	0.5	—	—	At bottom; when heated may stratify at points above bottom	Products of combustion, sewer gas, sludge. Also issues from carbonaceous strata.	Oxygen deficiency indicator
Carbon monoxide	CO	Chemical asphyxiant. Colorless, odorless tasteless, flammable. Poisonous.	0.97	Combines with hemoglobin of blood. Unconsciousness in 30 min at 0.2 to 0.25%. Fatal in 4 hr at 0.1%. Headache in few hr at 0.02%.	0.04	0.01	12.5	74.0	Near top, especially if present with illuminating gas.	Manufactured gas, flue gas, products of combustion, motor exhausts. Fires of almost any kind.	CO ampoules
Chlorine	Cl_2	Irritant. Yellow green color. Choking odor detectable in very low conc. Nonflammable.	2.49	Irritates respiratory tract. Kills most animals in very short time at 0.1%.	0.0004	0.0001	—	—	At bottom.	Chlorine cylinder and feed line leaks.	Detectable odor at low concentrations
Gasoline	C_5H_{12} to C_9H_{20}	Volatile solvent. Colorless. Odor noticeable at 0.03%. Flammable.	3.0 to 4.0	Anesthetic effects when inhaled. Rapidly fatal at 2.4%. Dangerous for short exposure at 1.1 to 2.2%.	0.4 to 0.7	0.10	1.3	6.0	At bottom.	Service stations, garages, storage tanks, and houses.	1. Combustible gas indicator 2. Oxygen deficiency indicator†
Hydrogen	H_2	Simple asphyxiant. Colorless, odorless, tasteless. Flammable.	0.07	Acts mechanically to deprive tissues of oxygen. Does not support life.	—	—	4.0	74.0	At top.	Manufactured gas, sludge digestion tank gas, electrolysis of water. Rarely from rock strata.	Combustible gas indicator

* Percentages shown represent volume of gas in air.
† For concentration over 0.3 per cent.

TABLE 20–1.—*Continued*

Gas	Chemical Formula	Common Properties*	Specific Gravity or Vapor Density (Air = 1)	Physiological Effect*	Max Safe 60-Min Exposure (% by Vol. in Air)	Max Safe 8-Hr Exposure (% by Vol. in Air)	Explosive Range (% by Vol. in Air)		Likely Location of Highest Conc.	Most Common Sources	Simplest and Cheapest Safe Method of Testing
							Lower Limit	Upper Limit			
Hydrogen sulfide	H_2S	Irritant and poisonous volatile compound. Rotten egg odor in small conc. Exposure for 2 to 15 min at 0.01% impairs sense of smell. Odor not evident at high conc. Colorless. Flammable.	1.19	Impairs sense of smell rapidly as conc. increases. Death in few min at 0.2%. Exposure to 0.07 to 0.1% rapidly causes acute poisoning. Paralyzes respiratory center.	0.02 to 0.03	0.002	4.3	46.0	Near bottom, but may be above bottom if air is heated and highly humid	Coal gas, petroleum, sewer gas. Fumes from blasting under some conditions. Sludge gas.	1. H_2S ampoule 2. 5% by wt. lead acetate soln.
Methane	CH_4	Simple asphyxiant. Colorless, odorless, tasteless. Flammable.	0.55	Acts mechanically to deprive tissues of oxygen. Does not support life.	Probably no limit, provided oxygen percentage is sufficient for life.	—	5.0	15.0	At top, increasing to certain depth.	Natural gas, sludge gas, manufactured gas, sewer gas. Strata of sedimentary origin. In swamps or marshes.	1. Combustible gas indicator 2. Oxygen deficiency indicator
Nitrogen	N_2	Simple asphyxiant. Colorless, tasteless. Nonflammable. Principal constituent of air (about 79%).	0.97	Physiologically inert.	—	—	—	—	Near top, but may be found near bottom.	Sewer gas, sludge gas. Also issues from some rock strata.	Oxygen deficiency indicator
Oxygen (in air)	O_2	Colorless, odorless, tasteless. Supports combustion.	1.11	Normal air contains 20.93% of O_2. Man can tolerate down to 12%. Min safe 8-hr exposure, 14 to 16%. Below 10% dangerous to life. Below 5 to 7% probably fatal.	—	—	—	—	Variable at different levels.	Oxygen depletion from poor ventilation and absorption, or chemical consumption of oxygen.	Oxygen deficiency indicator
Sludge gas	—‡	Mostly a simple asphyxiant. May be practically odorless, colorless. Flammable.	Variable	Will not support life.	No data. Would vary widely with composition.	—	5.3	19.3	Near top of structure	From digestion of sludge.	See components

‡ Mostly methane and carbon dioxide, with small amounts of hydrogen, nitrogen, hydrogen sulfide, and oxygen; occasionally traces of carbon monoxide.

3. A mixture of the gas and oxygen in the proper proportions, and
4. A source of ignition (open lights, sparks, hot filaments).

Every flammable gas or mixture of such gases has a lower and upper explosive limit based on the percentage by volume of the gases with air. Only between these limits will flame propagate. The leanest mixture with air that will explode is called the lower explosive limit. The richest mixture with air that will explode is called the upper explosive limit. The explosive range lies between these limits. Table 20–1 gives these limits for commonly encountered gases.

20.42 Sources of Toxic Gases and Vapors

1. Any manhole or tightly covered pit or tank. No tightly covered structure is safe until tests prove it so.

2. Screening, detriting, and comminuting facilities in enclosed areas. Gases or vapors which may be discharged through the open inlet sewer will accumulate in such areas.

3. Digested sludge pump rooms or pits, especially those in confined areas below grade. The hazard exists if sludge is allowed to accumulate on the floor through leakage or an open valve on the pumps.

4. Digested sludge storage tanks, open at the top, located in enclosures.

5. Sludge digestion tanks. Filled digesters present no explosion hazard. Fires may occur, however, at any point of gas leakage, such as from a leaking petcock or a pressure-vacuum relief assembly on the digester roof. Partially dewatered digesters containing digested sludge present a serious explosion hazard. Such digesters contain air and methane. If the air and methane become mixed in the right proportions and there is a source of ignition, an explosion will result.

6. Sludge gas piping and appurtenances in confined areas. Appurtenances include manometers, condensate traps, pressure regulators, flame traps, gas compressors, gas storage tanks, and gas boilers. The danger is from gas leakage.

7. Chlorine storage rooms.

20.43 Avoiding the Dangers from Noxious Gases or Vapors

1. In deep manholes, pits, and tanks*:

(*a*) Test for flammable or explosive gases or vapors with a portable combustible gas indicator.
(*b*) Test for hydrogen sulfide gas with hydrogen sulfide ampoules.
(*c*) Test for carbon monoxide gas, if illuminating gas leakage is possible, with carbon monoxide ampoules.
(*d*) Test for oxygen deficiency with an oxygen deficiency indicator.
(*e*) Observe any foreign odor or irritation to the eyes.

The equipment for making these tests is fully described in the Federation's Manual of Practice No. 1, *Safety in Wastewater Works,* except for the hydrogen sulfide ampoules. These ampoules, now commercially available, are used in similar fashion to carbon monoxide ampoules, described in Manual No. 1. Exposure time, however, is only for one minute and the color of the ampoule is immediately compared with the safety color chart provided.

2. In screening, detriting, and comminuting facilities in enclosed areas:

(*a*) Use explosion-proof electrical equipment, ban smoking or open lights.
(*b*) Provide ample ventilation by natural air draft or mechanical means or both.

* Not every structure in this class at treatment plants requires these tests. The structure's location, construction, and purpose are guides to the need for testing.

3. In digested sludge pump rooms:

(*a*) Avoid sludge spillage.
(*b*) Provide ample ventilation. In basements, use positive means for forced ventilation.

4. For digested sludge storage tanks, open at the top, and located in enclosures:

(*a*) See Items 2 (*a*) and 2 (*b*).
(*b*) Check atmosphere periodically with a combustible gas indicator for presence of flammable gas or use an automatic combustible gas alarm.

5. Before entering empty or nearly empty sludge digestion tanks:

(*a*) Test for flammable gas, hydrogen sulfide, and oxygen deficiency.
(*b*) Introduce compressed air or air from a portable air blower through a manhole with all other manholes open; continue ventilation while working inside the tank.

6. For filled sludge digestion tanks in operation:

(*a*) Avoid all sources of ignition in the vicinity of such tanks.
(*b*) Prevent continuous operation of the roof gas-pressure relief assembly by adjusting the waste-gas burner pressure relief to take all unused gas through the waste burner.
(*c*) Keep digesters full at all times.
(*d*) Always have one terminus of digested sludge withdrawal pipes valved open to prevent the building up of excessive gas pressures.

7. In confined areas containing sludge gas piping and appurtenances:

(*a*) Check all piping and appurtenances for gas leakage at regular intervals with a portable combustible gas indicator.
(*b*) Maintain a positive gas pressure in all lines.
(*c*) Use only approved types of manometers, condensate traps, pressure regulators, and flame traps. The use of unvalved, open-end U-tubes as manometers or condensate traps in enclosed structures is a hazard of the first magnitude. They should never be used. Avoid float-operated drip traps unless the condensate is tightly piped to the outside. All atmospheric reliefs for pressure regulators should be piped to the outside. Service all of these appurtenances regularly.
(*d*) Avoid water-seal gas compressors inside structures. Many of these develop serious gas leaks. Totally enclosed, dry-type compressors are recommended.
(*e*) Purge and refill gas storage tanks in accordance with instructions in the Federation's Manual of Practice No. 1.
(*f*) Check gas boiler safety devices regularly, especially the pilot or ignition safety cutoff.

8. In chlorine storage rooms:

(*a*) Remember the basic facts about chlorine: it is extremely irritating when inhaled; its choking odor is detectable in very low concentrations; it will not burn or explode; it is heavier than air.
(*b*) Have two chlorine canister gas masks available outside the storage room. For serious leaks, use a hose mask or compressed-air demand-type mask.
(*c*) Obtain and study the "Chlorine Manual" available free from the Chlorine Institute, Inc., 50 East 41st Street, New York 17, New York.

20.44 Respiratory Protective Apparatus

The hose mask or compressed-air demand-type mask is recommended for

respiratory protection in manholes and other enclosed structures, when required. A full discussion of respiratory protection will be found in the Federation's Manual of Practice No. 1.

20.45 Artificial Respiration

The Federation's Manual of Practice No. 1 gives resuscitation (artificial respiration) procedures in detail.

20.5 PREVENTION OF IONIZING RADIATIONS

Where radioactive isotopes are in extensive use by industries, research institutions, or hospitals, the possibility of careless or accidental discharge of these materials must be considered. A hazard from ionizing radiations might occur in a localized area such as a sewage wet well, or the sludge being handled at a sewage plant might become radioactive. Portable radiation detection meters are not difficult to acquire, but some training in their use is required. Civil defense and other training organizations commonly offer instruction on these matters.

MEETINGS OF INTEREST

May 15–16	**Water Pollution in the Great Lakes Area,** De Paul University, Chicago, Ill. The Rev. John R. Cortelyou, Dept. of Biological Sciences, De Paul University.
May 25–26	**10th Pacific Industrial Waste Conference,** Washington State University, Pullman, Wash. William H. Knight, Washington State Institute of Technology, Washington State University, Pullman, Wash.
May 29–June 3	**International Water Supply Association, Fifth Congress,** Congress Hall, West Berlin, Germany. International Water Supply Association, 34 Park St., London W. 1, England.
June 4–9	**American Water Works Association,** Cobo Hall, Detroit, Mich. Raymond J. Faust, AWWA, 2 Park Ave., New York 16.
June 5–7	**7th Sewage Works School for Operators,** Washington State University, Pullman, Wash. William H. Knight (see address above).
June 6–8	**Second National Congress on Environmental Health,** University of Michigan School of Public Health.
June 8–10	**Manufacturing Chemists' Association,** Greenbrier, White Sulphur Springs, W. Va.
June 11–14	**Air Pollution Control Association,** Commodore Hotel, New York, N. Y.
June 19–21	**Rudolfs Research Conference,** Department of Sanitation, Rutgers University, New Brunswick, N. J. Dr. H. Heukelekian, Chairman, Dept. of Sanitation, Rutgers University.
June 25–26	**American Society for Testing Materials,** Chalfonte-Haddon Hall, Atlantic City, N. J.
July 4–7	**National Society of Professional Engineers,** Olympic Hotel, Seattle, Wash. Kenneth E. Trombley, NSPE, 2029 K St., N. W., Washington 6, D. C.

TIPS AND QUIPS

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Manufacturing Chemists' Association and Pollution Control

Industry in general and the chemical industry in particular are aware of and are taking action to solve serious problems arising from the complex society in the area of environmental health, according to General John E. Hull, President of the Manufacturing Chemists' Association.

In an address before the 53rd Annual Meeting of the American Institute of Chemical Engineers, General Hull emphasized the intense degree of responsibility of the chemical industry in air and water pollution abatement, industrial medicine and safety, hazardous-substances labeling, and assuring the nation of an adequate and safe food supply.

In citing just one area, that of water pollution abatement, General Hull pointed to a "set of principles" now being arrived at by experts working in the MCA Water Pollution Abatement Committee.

Among them, he said, were:

1. Proper control of stream pollution is one of the obligations of responsible corporate citizenship.

2. Avoiding harmful pollution is a necessary business cost. As with other aspects of business, qualified people with clearly defined responsibilities must be assigned to bring and keep pollution under control.

3. The chemical industry recognizes the community nature of water pollution control and desires to cooperate fully with the control agencies that are responsible for safeguarding the health and welfare of the people.

4. The solution of stream pollution problems of the individual companies is not a determining factor in competitive production and, therefore, the knowledge pertaining to solution of these problems should be freely shared.

Throughout the chemical industry, General Hull stated, there is carried out "a positive program for the specific purpose of recognizing hazards to health and safety." This program involves the planned study of harmful properties and the appropriate consideration of these properties in the development and in the manufacture of new products and new uses.

Despite all these advances, the MCA President stated, "unfortunately there are matters about which we are far less confident, a current and outstanding example being the testing for carcinogenic properties. The total effort expended in this testing is substantial and quite expensive. As time goes on we can expect improvement in methods and understanding, but we will always have technical questions."

The head of the national chemical organization stressed the fact that rather than being individual problems for individual segments of our society, "all problems in this field, as in most others, become problems of (the entire) society."

An example, General Hull said, can be found in the area of certain synthetic detergents. "These are products which the housewife would not wish to give up. However, they have had a technological impact on the sewage problems in many areas and on the water supply of many communities.

As problems have become apparent, hundreds of thousands of dollars of research work has been accomplished by industry. If and when it is decided that these otherwise beneficial products are creating too great a hazard in the streams, then certainly society—of which we all are a part—may feel the consequences in terms of a poorer or different performance by some other product, possibly at an increased cost.

"Another way of expressing this point is that more and more solutions to the problems of environmental health will be found at the level of society. This is where I think the answer lies," General Hull said.

Fish-Kills

The United States Public Health Service recently announced first reports from 31 states indicate that agricultural pesticides and industrial wastes caused 70 per cent of the 185 pollution-caused fish-kills along more than 600 miles of streams and 5,000 acres of lakes during a nation-wide federal-state cooperative study from June to October 1960.

The continuing national collection of reports of fish-kills began several months ago between the Public Health Service and the states to get some indication of their prevalence and causes on a nationwide basis.

This first study of stream fish-kills showed that agricultural poisons accounted for the largest number, or 73 out of the total 185 state reports. Industrial wastes were listed as the cause in 57, domestic sewage was listed 15 times (or eight per cent), while other causes—pipeline breaks, shipping pollution, etc.—numbered 17 fish-kills, and unknown causes, 28. In some instances, one or more causes were listed.

Approximately half of the reports received by the Service gave estimates of total fish-kills, ranging, with one exception, from 100 to 182,000 and averaging 6,100 fish per kill by pollution. One large unrepresentative single pollution kill of 5 million fish (mostly trash and forage types) was caused by industrial wastes in the Kanawha River during two days in August over a distance of 19 miles.

The Public Health Service reported that quarterly summaries of raw data without technical interpretation are being provided state cooperators, the United States Fish and Wildlife Service, and other organizations and individuals upon request.

Pollution Causes Suits for Damages *

The little town of Phippsburg near the mouth of the Kennebec River in Maine has been authorized in a special town meeting to take legal action against upriver communities, industries, and individuals contributing pollution to the Kennebec and Androscoggin Rivers.

Authorization to institute suits totaling $40 million for damages was recommended by the Selectmen. The Maine Water Improvement Commission and the Sea and Shore Fisheries Department recently disclosed that discharges of industrial wastes and sewage have closed clam flats estimated to be worth hundreds of thousands of dollars annually to the town and its residents, and threaten the closing of Popham Beach for recreational activities. The town claims that the pollution has also depressed real estate values and promoted harmful publicity.

What's in a Name?

In the District of Columbia a firm may not use the name "engineers" in its title unless it hires professional engineers who are registered in the District of Columbia, the Municipal Court of Appeals ruled. In this particular case a television repair shop was fined.

* From the *Newsletter* of the New England Interstate Water Pollution Control Commission, Vol. 11, No. 3 (1960).

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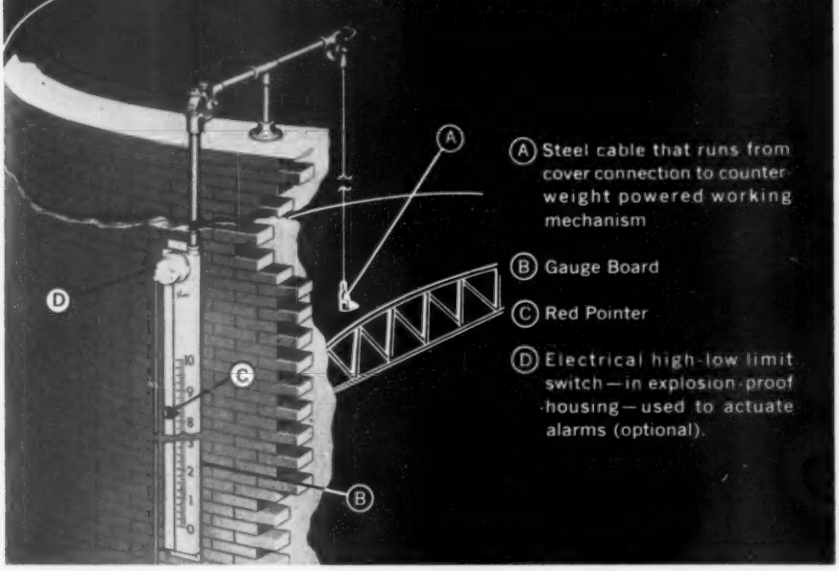
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Komline-Sanderson Engr. Corp.
Link-Belt Co.
Nichols Engr. & Research Corp.
Stuart Corp.

Ejectors
Komline-Sanderson Engr. Corp.
Smith & Loveless
Tex-Vit Mfg. Co.
Yeomans Brothers Co.

Engineers (*see* Professional Services, elsewhere in this issue)

Engines (Sludge Gas and Petroleum Fuels)
Fairbanks, Morse & Co.
Waukesha Motor Co.
Worthington Corp.

Fans (*also see* Air Compressors, Blowers, and Compressors)
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Lakeside Engineering Corp.
Westinghouse Electric Corp.

Filter Equipment, Trickling
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American Well Works
Ralph B. Carter Co.
Dorr-Oliver Inc.
Dow Chemical Co.
Eimco Corp.
Filtration Equipment Corp.
Industrial Materials Co.
Infilco Inc.
Keasbey & Mattison Co.
Komline-Sanderson Engr. Corp.
Lakeside Engineering Corp.
Nichols Engr. & Research Corp.
Pacific Flush Tank Co.
Smith & Loveless
Trickling Filter Floor Inst.
Walker Process Equipment Inc.
Yeomans Brothers Co.
Zimmer & Francescon

Filter Materials
Carborundum Co.
Filtration Equipment Corp.
Glenn Chemical Co.
Graver Water Conditioning Co.
Industrial Materials Co.
Johns-Manville Sales Corp.

Filters, Diatomaceous Earth
Graver Water Conditioning Co.
Yeomans Brothers Co.

Filters, Vacuum (*also see* Vacuum Filters)
Bird Machine Co.
Dorr-Oliver Inc.
Eimco Corp.
Proportioneers Div., B-I-F Industries

Flocculating Equipment
Alpha Ltd. (Switzerland)
American Well Works
Ralph B. Carter Co.
Chain Belt Co.
Dorr-Oliver Inc.
Eimco Corp.
Graver Water Conditioning Co.
Hardinge Co., Inc.
Infilco Inc.
Jeffrey Mfg. Co.
Lakeside Engineering Corp.
Link-Belt Co.
Permutit Co., Div. of Pfaudler Permutit Inc.
Stuart Corp.
Walker Process Equipment Inc.
Webster Mfg., Inc.
Zimmer & Francescon

Flotation Equipment
Chain Belt Co.
Dorr-Oliver Inc.
Eimco Corp.
Graver Water Conditioning Co.
Komline-Sanderson Engr. Corp.
Yeomans Brothers Co.

Flow Measurement
Burgess-Manning Co., Penn Instruments Div.
Filtration Equipment Corp.

Gas Control Equipment
Alpha Ltd. (Switzerland)
Burgess-Manning Co., Penn Instruments Div.
Ralph B. Carter Co.
Chicago Pump Co.
Dorr-Oliver Inc.
Eimco Corp.
Foxboro Co.
Homestead Valve Mfg. Co.
Pacific Flush Tank Co.
Rockwell Mfg. Co.
Vapor Recovery Systems Co.
Walker Process Equipment Inc.
Zimmer & Francescon

Gas Diffusers (*see* Diffusers, Gas)

Gas Holders, Boilers, and Appurtenances
Ralph B. Carter Co.
Chicago Pump Co.
Dorr-Oliver Inc.
Eimco Corp.
Johns-Manville Sales Corp.
Walker Process Equipment Inc.

Gaskets
Johns-Manville Sales Corp.
Keasbey & Mattison Co.

Gates
Armco Drainage & Metal Products, Inc.
Filtration Equipment Corp.
Industrial Materials Co.
Snow Gates & Valves, Inc.
Webster Mfg., Inc.

Generators
Fairbanks, Morse & Co.
General Electric Co.
Westinghouse Electric Corp.
Worthington Corp.

Grinders (*also see* Shredders and Grinders)
Alpha Ltd. (Switzerland)
American Well Works
Chain Belt Co.
Dorr-Oliver Inc.
Gruendler Crusher & Pulverizer Co.
Jeffrey Mfg. Co.
Yeomans Brothers Co.

Grit Collection and Conditioning Equipment
Alpha Ltd. (Switzerland)
American Well Works
Chain Belt Co.
Chicago Pump Co.
Dorr-Oliver Inc.
Eimco Corp.
Infilco Inc.
Jeffrey Mfg. Co.
Link-Belt Co.
Stuart Corp.
Walker Process Equipment Inc.
Webster Mfg., Inc.
Zimmer & Francescon

PROCEEDINGS OF MEMBER ASSOCIATIONS

MICHIGAN SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

The Michigan Sewage and Industrial Wastes Association held its 35th Annual Meeting at the Park Place Hotel, Traverse City, May 23–25, 1960. A total of 205 members and 33 guests were registered, in addition to 57 ladies. This was the largest number of persons ever attending an annual conference.

The technical conference was opened with a discussion of developments in sewage and industrial waste collection and treatment throughout the state during the past year, the present status of pollution control projects, and the progress made in operation of sewage treatment plants was discussed by Donald M. Pierce, Chief Engineer in Charge of Sewerage and Sewage Treatment, Michigan Department of Health. Dr. William D. Hatfield, Past-President of the Federation, extended greetings and outlined activities of other associations and of the Federation during the past year. Loring F. Oeming, Chief Engineer, Michigan Water Resources Commission, presented a paper on municipal sewage treatment plant construction under the federal grant program, commenting specifically on the mechanics of this program as administered in Michigan and its influence on the progress of construction. Samuel D.

(*Continued on page 267a*)

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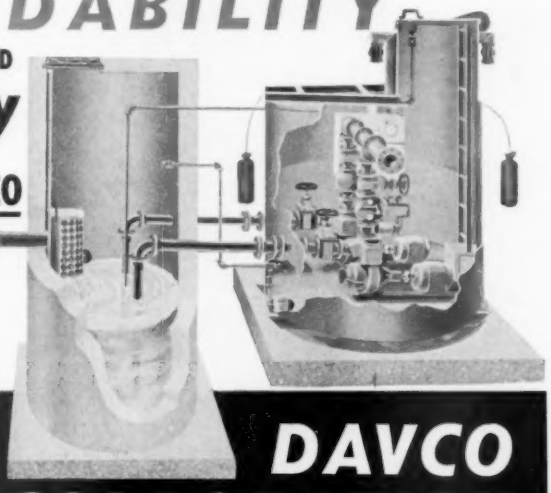

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Infilco Inc.
Link-Belt Co.
Pacific Flush Tank Co.
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National Water Main Cleaning Co.

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Eimco Corp.
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Walker Process Equipment Inc.
Wemco Div., Western Machinery Co.

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Keasbey & Mattison Co.

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Cast Iron Pipe Research Assn.
Industrial Materials Co.
U. S. Pipe & Foundry Co.
R. D. Wood Co.

Pipe, Clay
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National Clay Pipe Mfrs., Inc.
National Sewer Pipe Ltd. (Canada)
Robinson Clay Product Co.

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Stebbins Engr. & Mfg. Co.

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American-Marietta Co.
American Pipe & Construction Co.
Gray Concrete Pipe Co., Inc.
Lock Joint Pipe Co.
National Sewer Pipe Ltd. (Canada)
Portland Cement Assn.
Price Brothers Co.

Pipe, Fiber
Sonoco Products Co.

Pipe Fittings
American Cast Iron Pipe Co.
Cast Iron Pipe Research Assn.
Keasbey & Mattison Co.
National Sewer Pipe Ltd. (Canada)
Price Brothers Co.
Robinson Clay Product Co.
Smith-Blair, Inc.
U. S. Pipe & Foundry Co.
R. D. Wood Co.

Pipe Jointing Materials (*see* Jointing Materials)

Pipe, Plastic
Amercoat Corp.
Evanite Plastic Co.

Pipe, Repairs
Centriline Corp.
Smith-Blair, Inc.

Pipe, Steel
American Pipe & Construction Co.
Armco Drainage & Metal Products, Inc.
Keasbey & Mattison Co.
A. O. Smith Corp.

Plastic Pipe Products
Amercoat Corp.
Evanite Plastic Co.
Keasbey & Mattison Co.

Publications
American City Magazine
Engineering News-Record
Liverpool University Press (England)
Public Works Magazine
Wastes Engineering Magazine
Water & Sewage Works
John Wiley & Sons, Inc.

Pump Controls
Builders-Providence Div., B-I-F Industries
Burgess-Manning Co., Penn Instruments Div.
Chicago Pump Co.
Fischer & Porter Co.
Foxboro Co.
General Electric Co.
Minneapolis-Honeywell Regulator Co., Brown Instruments Div.
Rockwell Mfg. Co.
Smith & Loveless
Westinghouse Electric Corp.
Worthington Corp.
Zimmer & Francescon

Porter, Consulting Engineer, McNamee, Porter and Seeley, discussed the design and construction of the additions to the Traverse City sewage treatment plant. This discussion was followed by an inspection trip of this plant.

The morning session on Tuesday was in the nature of a symposium on sewage treatment. The following subjects were discussed:

"Digester Cleaning at Niles Sewage Treatment Plant," by Ralph A. Garno, Superintendent.

"Digester Reconditioning at Kalamazoo," by Leonard M. Pratt, Superintendent.

"Fiber Waste Effect on Digester Operation at Cheboygan Sewage Treatment Plant," by Archie L. Beebe, Superintendent.

"Sludge Filtering at East Lansing," by Edgar Sneiders, Superintendent.

"Effect of One Industrial Waste on a Municipal Sewer," by Michael A. Groen, Superintendent, Dearborn.

"Nitrification of Oxygen Demand Dilution Water," by Harry E. McEntee, Superintendent, Mt. Clemens.

"Sludge Flotation at Wayne County Airport Sewage Treatment Plant," by Harold M. Leonhard, Superintendent.

The Tuesday afternoon session was a symposium on industrial waste treatment embracing the following discussions:

"Spray Irrigation Waste Disposal at Welch Grape Juice Company, Lawton, Mich.," by W. A. Baker, Michigan Plants Manager.

"Industrial Waste Treatment at Fisher Body–Willow Run Plant," by A. M. McCurdy, Chemical Engineer, Fisher Body Division, General Motors Corp.

"Coagulants and Coagulant Aids in Waste Treatment," by Stanley Mogel-

(*Continued on page 269a*)

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Pumps, Gas
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Sutorbilt Corp.

Pumps, Grit
Nagle Pumps, Inc.

Pumps, Sewage
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American Well Works
Aurora Pump Div., The New York Air Brake Co.
Chicago Pump Co.
Davco Corp.
Eimco Corp.
Fairbanks, Morse & Co.
Gorman-Rupp Co.
Infilco Inc.
Marlow Pumps, Div. of Bell & Gossett Co.
Smith & Loveless
Sutorbilt Corp.
Wallace & Tiernan Inc.
Wemco Div., Western Machinery Co.
Worthington Corp.
Yeomans Brothers Co.
Zimmer & Francescon

Pumps, Sludge
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American Well Works
Aurora Pump Div., The New York Air Brake Co.
Ralph B. Carter Co.
Chicago Pump Co.
Dorr-Oliver Inc.
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Nagle Pumps, Inc.
Sutorbilt Corp.
Wallace & Tiernan Inc.
Wemco Div., Western Machinery Co.
Worthington Corp.
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Zimmer & Francescon

Pumps, Vacuum
Roots-Connersville Blower, Div. of Dresser Industries Inc.
Sutorbilt Corp.

Pumps, Water
American Well Works
Aurora Pump Div., The New York Air Brake Co.
Ralph B. Carter Co.
Chain Belt Co.
Chicago Pump Co.
Eimco Corp.
Fairbanks, Morse & Co.
Gorman-Rupp Co.
Marlow Pumps, Div. of Bell & Gossett Co.
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Worthington Corp.
Yeomans Brothers Co.
Zimmer & Francescon

Radiation Monitoring Equipment
Westinghouse Electric Corp.

Radios, Mobile
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Minneapolis-Honeywell Regulator Co., Brown Instruments Div.
Ohmart Corp.
Wallace & Tiernan Inc.

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Lakeside Engineering Corp.

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Chicago Pump Co.
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Infilco Inc.
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Walker Process Equipment Inc.
Zimmer & Francescon

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Eimco Corp.
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Jeffrey Mfg. Co.
Komline-Sanderson Engr. Corp.
Lakeside Engineering Corp.
Link-Belt Co.
Walker Process Equipment Inc.
Webster Mfg., Inc.
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Dorr-Oliver Inc.
Gruendler Crusher & Pulverizer Co.
Jeffrey Mfg. Co.
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Ralph B. Carter Co.
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Infilco Inc.
Lakeside Engineering Corp.
Pacific Flush Tank Co.
Yeomans Brothers Co.

Sludge Concentrators
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Nichols Engr. & Research Corp.

Sludge Flotation Equipment (*see* Flotation Equipment)

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Dorr-Oliver Inc.
Eimco Corp.
Jeffrey Mfg. Co.
Link-Belt Co.
Nichols Engr. & Research Corp.
Walker Process Equipment Inc.
Zimmermann Process Div. of Sterling Drug Inc.

Sludge Removal Equipment
Jeffrey Mfg. Co.
Link-Belt Co.
Webster Mfg., Inc.
Zimmermann Process Div. of Sterling Drug Inc.

Sludge Shredders
Alpha Ltd. (Switzerland)
Gruendler Crusher & Pulverizer Co.
Jeffrey Mfg. Co.

Sprockets
Chain Belt Co.
Link-Belt Co.
Webster Mfg., Inc.

Steel Pipe Products
Armco Drainage & Metal Products, Inc.

Structural Metal
Alpha Ltd. (Switzerland)

Switchgears
Alpha Ltd. (Switzerland)
General Electric Co.
Westinghouse Electric Corp.
Worthington Corp.

Tanks
Chain Belt Co.
Link-Belt Co.
Preload Co., Inc.
A. O. Smith Corp.
Stebbins Engr. & Mfg. Co.

Tools
Flexible Inc.

Transformers
Alpha Ltd. (Switzerland)
General Electric Co.
Westinghouse Electric Corp.

Trickling Filter Equipment (*see* Filter Equipment, Trickling)

Trucks and Tractors
Eimco Corp.

Turbines
Worthington Corp.

Vacuum Filters (*also see* Filters, Vacuum)
Bird Machine Co.
Dorr-Oliver Inc.
Eimco Corp.
Komline-Sanderson Engr. Corp.
Proportioneers Div., B-I-F Industries

Valves and Gates
Armco Drainage & Metal Products, Inc.
Builders-Providence Div., B-I-F Industries
Chapman Valve Mfg. Co.
DeZurik Corp.
Filtration Equipment Corp.
Homestead Valve Mfg. Co.
Industrial Materials Co.
Iowa Valve Co.
Mueller Co.
Rockwell Mfg. Co.
Roots-Connersville Blower, Div. of Dresser Industries Inc.
Simplex Valve and Meter Co.
A. P. Smith Mfg. Co.
Snow Gates & Valves, Inc.
Westinghouse Electric Corp.
W-K-M Div. of ACF Industries, Inc.
R. D. Wood Co.
Yeomans Brothers Co.

Vessels (*see* Tanks)

Weighing Devices
Builders-Providence Div., B-I-F Industries
Fairbanks, Morse & Co.
Fisher Scientific Co.
Wallace & Tiernan Inc.

nicki, Sanitary Engineer, Dow Industrial Services, Dow Chemical Co.

"Waste Disposal System—Muskegon Ordinance Plant," by Clark Wheaton, Metallurgist in Charge of Waste Treatment, Continental Motors.

At the conclusion of these discussions, Gordon H. Stafford, Chairman of the Gadget Committee, presented and discussed several gadgets and innovations which had been developed by several of the members for competition in a gadget contest.

The final technical session on Wednesday morning included the following papers:

"Bottom Fauna Investigations Can Implement Waste Control," by Carlos M. Fetterolf, Jr., Aquatic Biologist, Michigan Water Resources Commission.

"Theory and Practice of High-Rate Activated Sludge Treatment of Sewage and Industrial Wastes," by W. Wesley Eckenfelder, Associate Professor of Civil Engineering, Manhattan College, New York.

"Experience with Contact Stabilization at the Birmingham Sewage Treatment Plant," by Russell Grinnell, Superintendent.

"Automatic Sampler for River Monitoring Program at Pontiac," by Arthur E. Maass, Assistant Superintendent of that plant.

The Bedell Award for extraordinary service to the Michigan Association was presented to Harland P. Dodge, Sanitary Engineer, Francis Engineering Co., Saginaw, and the Hatfield Award for outstanding treatment plant operation went to C. Preston Witcher, Superintendent, Ann Arbor.

At the annual business meeting the following officers were elected or continued in office:

President: Fred Galarno, Saginaw.

(*Continued on page 270a*)

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Join and support your local Member Association. For the name and address of the secretary to be contacted see page 234a.

1st Vice-President: Robert F. Killeen, Detroit.

2nd Vice-President: Ralph A. Garno, Niles.

Secretary-Treasurer: Donald M. Pierce, Lansing.

DONALD M. PIERCE
Secretary-Treasurer

THE INSTITUTE OF SEWAGE PURIFICATION

The Annual Conference of the Institute of Sewage Purification was held at Scarborough, England, June 21–24, 1960. Attendance totaled 620.

Among the papers presented were:

Symposium: "Progress Towards the Solution of the Synthetic Detergents Problem."

An introductory paper by A. Key, Senior Chemical Inspector, Ministry of Housing and Local Government.

"The Manufacturers' Part in the Luton Experiment," by G. V. V. Squires, Thomas Hedley & Co., Newcastle-upon-Tyne.

"Behaviour of a New Synthetic Detergent in Sewage-Treatment Processes," by G. E. Eden, and G. A. Truesdale.

"Analytical Problems in the Luton Experiment," by H. L. Bolton and P. J. Cooper, The Laboratory of the Government Chemists.

"Decrease in the Content of Surface-Active Material in the River Lee," by C. Hammerton, Senior Chemist, Metropolitan Water Board.

"Fuel Cells and Their Potentialities for Power Generation from Sludge Digestion Gas," by H. H. Chambers, Director of Research, Sondes Place Research Institute, Dorking, Surrey.

"Two-Stage Biological Sewage Treatment in Germany," by H. Rohde, Chief Engineer, Ruhrverband, Germany.

"An Ecological Approach to Some Bacteria Bed Problems," by H. A.

Hawkes, Biologist, Birmingham Tame and Rea District Drainage Board.

"A Recent Bacteriological and Epidemiological Study of Sewage Contamination in British Coastal Bathing Waters," by B. Moore, Director, Public Health Laboratories.

The following officers were elected:

President: M. A. Kershaw.
Vice-President: Martin Lovett.
Joint Secretary: W. F. A. Snook.
Treasurer: L. B. Phillipps.

W. F. A. Snook
Joint Secretary

PUERTO RICO WATER AND SEWAGE WORKS ASSOCIATION

The Puerto Rico Water and Sewage Works Association held its Annual Meeting at the San Juan Intercontinental Hotel, San Juan, Puerto Rico, July 8, 1960. The meeting consisted of a get-together cocktail party followed by a dinner. The ladies were entertained by a demonstration of facial treatment. Dick Sibley, Dorr-Oliver Inc., discussed package treatment plants.

Officers for the year 1960–61 are as follows:

President: Israel Rivera-Marini, Santurce.
Vice-President: Pedro Hernandez-Vega, Santurce.
Secretary-Treasurer: Robert J. Auld, Santurce.

Robert J. Auld
Secretary-Treasurer

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WPCF publications

Safety in Wastewater Works

Contains information on hazards, accident statistics, rescue methods, safe practices, and equipment. *56 pages. $0.75 to members; $1.50 to others. Order as Item MOP-1.**

Utilization of Sewage Sludge as Fertilizer

An authoritative evaluation of advantages and limitations of sludge as a soil conditioner. *120 pages. $0.75 to members; $1.25 to others. Order as Item MOP-2.**

Chlorination of Sewage and Industrial Wastes

Reviews history, development, and up-to-date technique of chlorine application. *90 pages. $1.00 to members; $1.25 to others. Order as MOP-4.**

Air Diffusion in Sewage Works

History and modern practice in design, installation, operation, and maintenance of diffuser systems and appurtenances. *75 pages. $1.00 to members; $1.25 to others. Order as Item MOP-5.**

Units of Expression for Wastes and Waste Treatment

Lists of recommended units for quantities ordinarily encountered in wastes and waste treatment. *8 pages. $0.25 to members; $0.50 to others. Order as Item MOP-6.**

Sewer Maintenance

A guide for maintaining a municipal or industrial drainage system in serviceable condition. *64 pages. $1.00 to members; $1.50 to others. Order as Item MOP-7.**

Sewage Treatment Plant Design

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PROFESSIONAL SERVICES, 273a–281a

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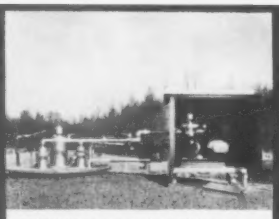
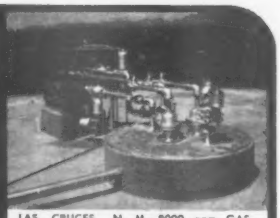
ROCKFORD, ILL.—Three GASLIFTERS in existing digesters. Henry Riedesel, Mgr., San. Dist. Greeley and Hansen, Chicago, Cons. Engrs.



GREENSBORO, N. C.—GASLIFTER in existing 75' dia. digester with floating cover. Dan Holder, Supt. City of Greensboro, Engrs.



LAS CRUCES, N. M.—8000 gpm GASLIFTER in 50' dia. digester with fixed cover. R. A. Smith, Supt. Gordon Herkenhoff & Assoc., Albuquerque, Cons. Engrs.

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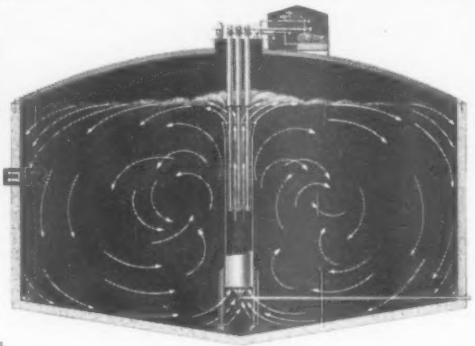

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AURORA, ILL.—10,000 gpm GASLIFTER in existing 50' sq. digester. Williard P. Pfeiffer, Supt. W. E. Deuchler, Assoc., Inc., Aurora, Cons. Engrs.

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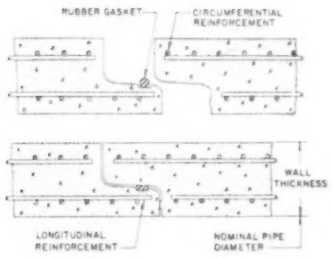

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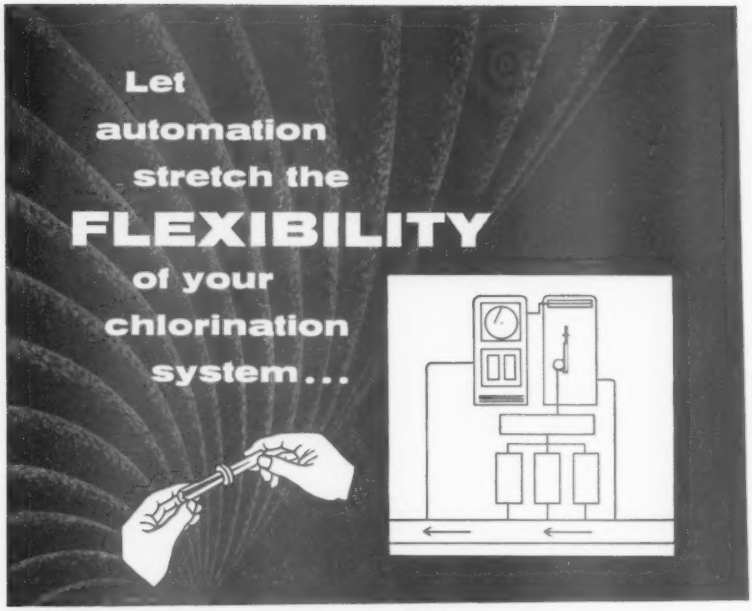

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